Title: VISUAL DISPLACEMENT
SENSOR
Inventor(s): Tatsuya Matsunaga, et al.
DOCKET NO.: 058856-0106

09/937480

Fig. 1

3 measurement object

4

5

100

sensor head unit — **1**

VS

CONT

7 console unit

sensor main unit — **2**

displacement measured value

image monitor — **6**

An overall view of a visual displacement sensor

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SENSOR
Inventor(s): Tatsuya Matsunaga, et al.
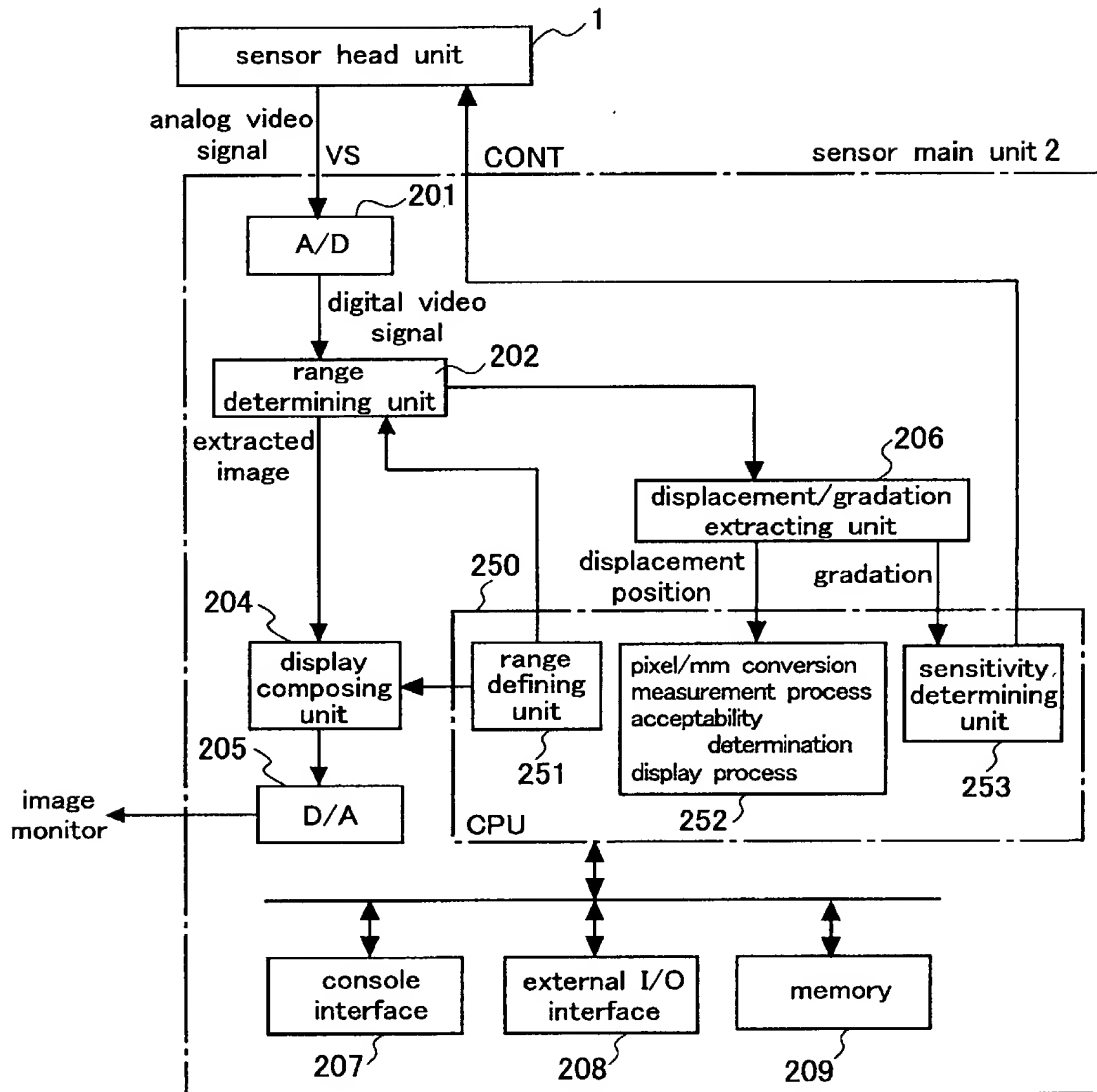DOCKET NO.: 058856-0106

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Fig. 2
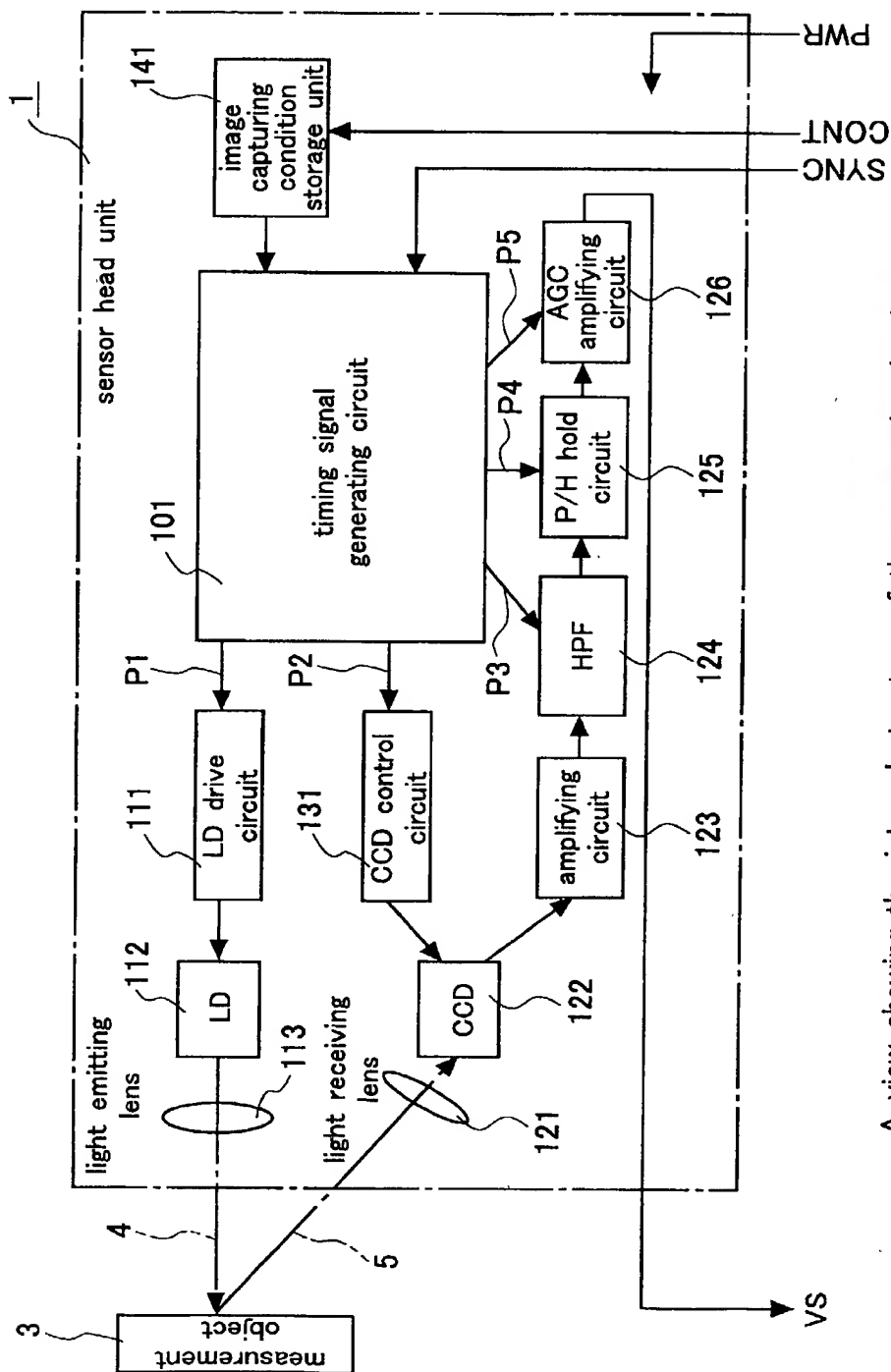
A view showing the internal structure of the sensor head unit

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Fig. 3

sensor head unit — 1

analog video signal — VS   CONT   sensor main unit 2

A/D — 201

digital video signal

range determining unit — 202

extracted image

displacement/gradation extracting unit — 206

displacement position   gradation

204 — display composing unit

250 — range defining unit — 251

pixel/mm conversion measurement process acceptability determination display process — 252

sensitivity determining unit — 253

205 — D/A   CPU

image monitor

console interface — 207

external I/O interface — 208

memory — 209

A block diagram (part 1)
showing the functional internal structure of the sensor main unit

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Fig. 4
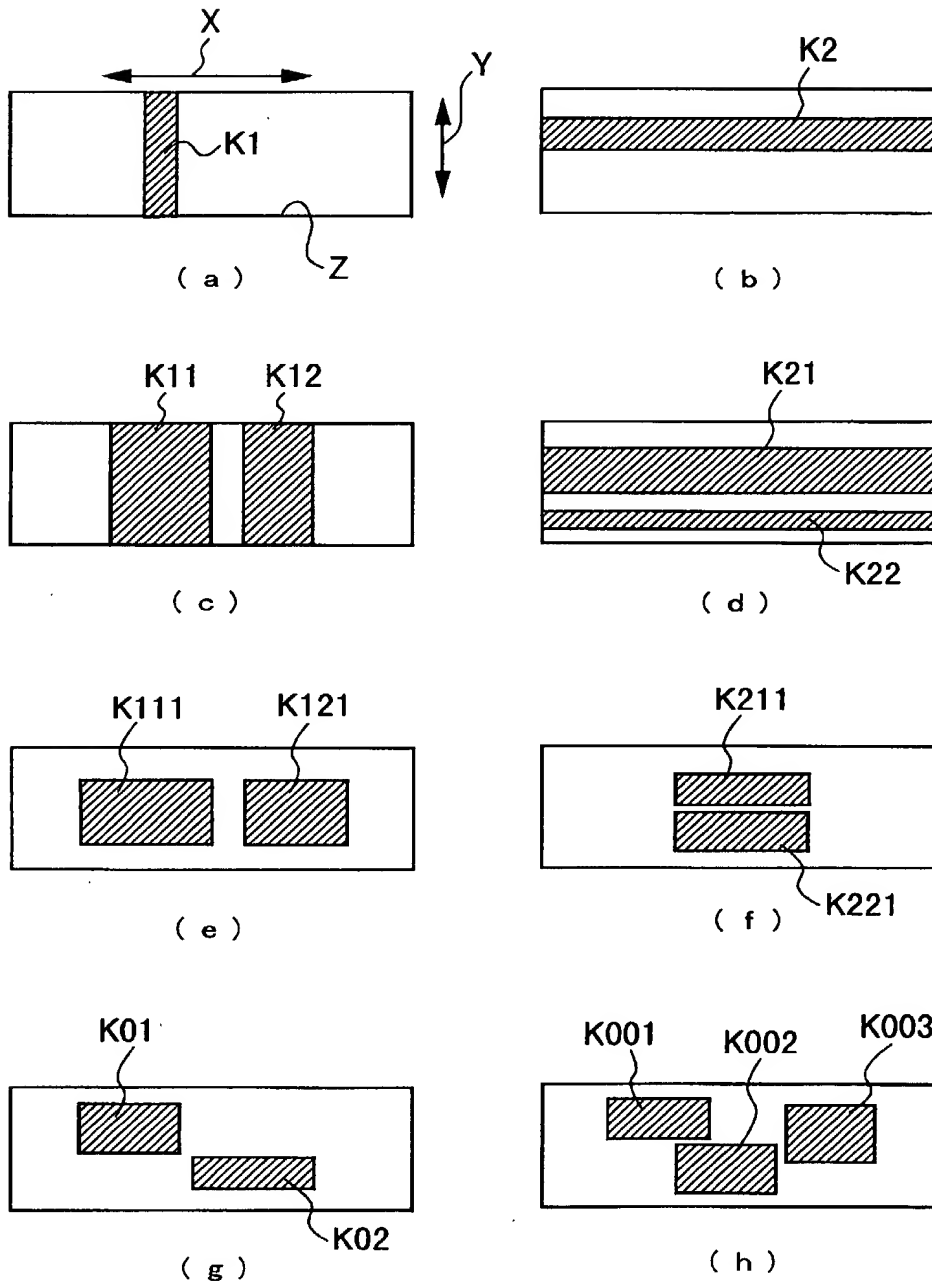
A view showing a mode of defining measurement object ranges

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SENSOR
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09/937480

Fig. 5

```
                    ┌─────────────┐
                    │    START    │
                    └─────────────┘
                           │
                           ▼
        ┌──────────────────────────────────┐
        │  obtain image from sensor head    │──── 501
        └──────────────────────────────────┘
                           │
                           ▼
        ┌──────────────────────────────────┐
        │  extract characteristic points    │──── 502
        │  in measurement object range      │
        └──────────────────────────────────┘
                           │
                           ▼
        ┌──────────────────────────────────┐
        │  extract line bright containing   │──── 503
        │  characteristic points            │
        └──────────────────────────────────┘
                           │
                           ▼
        ┌──────────────────────────────────┐
        │  extract measuring point coordinate│──── 504
        │  on line bright by using prescribed│
        │  measurement method               │
        └──────────────────────────────────┘
                           │
                           ▼
        ┌──────────────────────────────────┐
        │  compute displacement from        │──── 505
        │  measurement point coordinates    │
        └──────────────────────────────────┘
                           │
                           ▼
        ┌──────────────────────────────────┐
        │  display on image monitor and     │──── 506
        │  send signal to external output   │
        └──────────────────────────────────┘
                           │
                           ▼
                    ┌─────────────┐
                    │     END     │
                    └─────────────┘
```
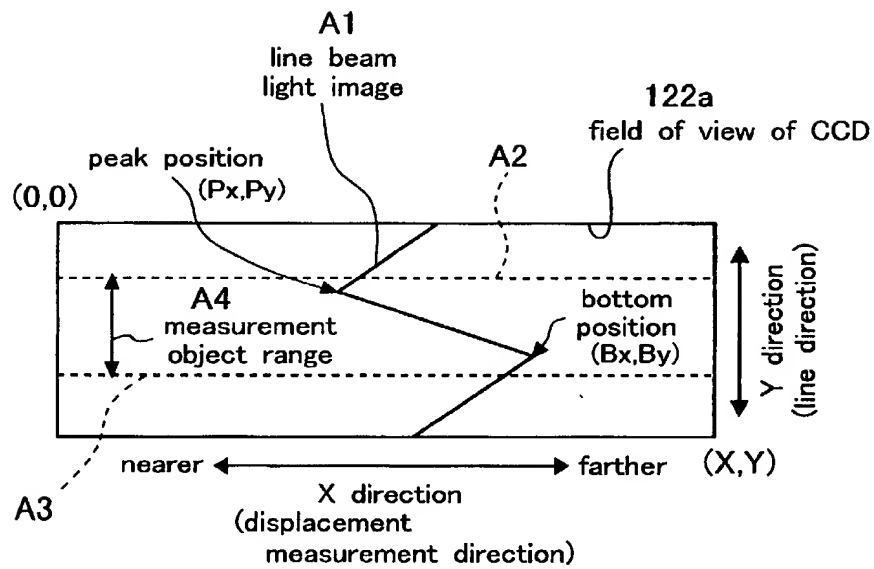
A general flow chart schematically illustrating the operation
of the displacement measurement by the sensor main unit

Title: VISUAL DISPLACEMENT
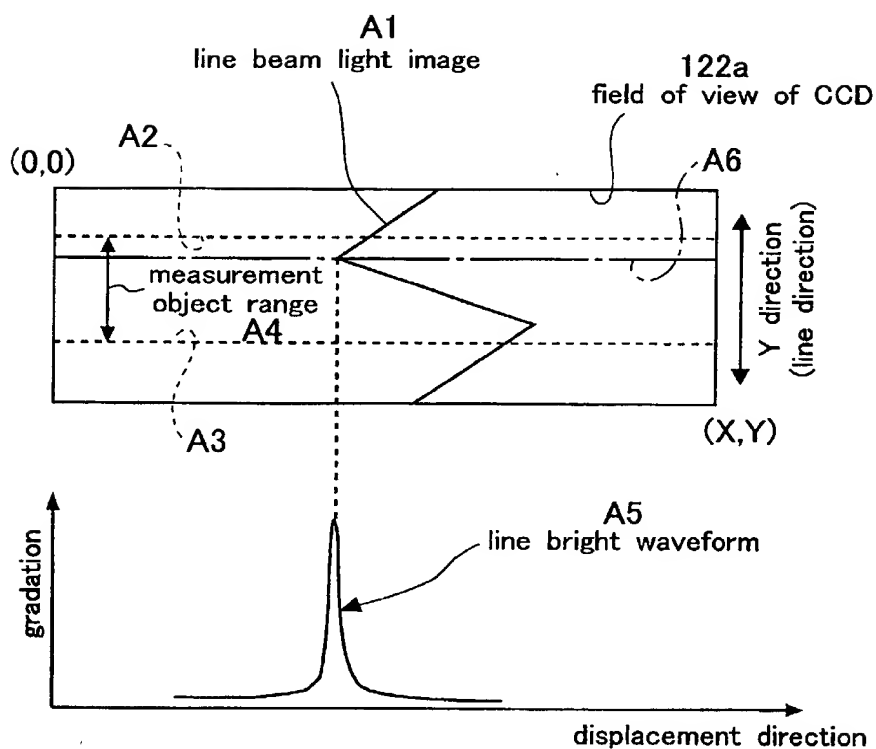SENSOR
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Fig. 6

A1
line beam light image

122a
field of view of CCD

(0,0)

Y direction
(line direction)

nearer ◄――――――――► farther (X,Y)

X direction (displacement
measurement direction)
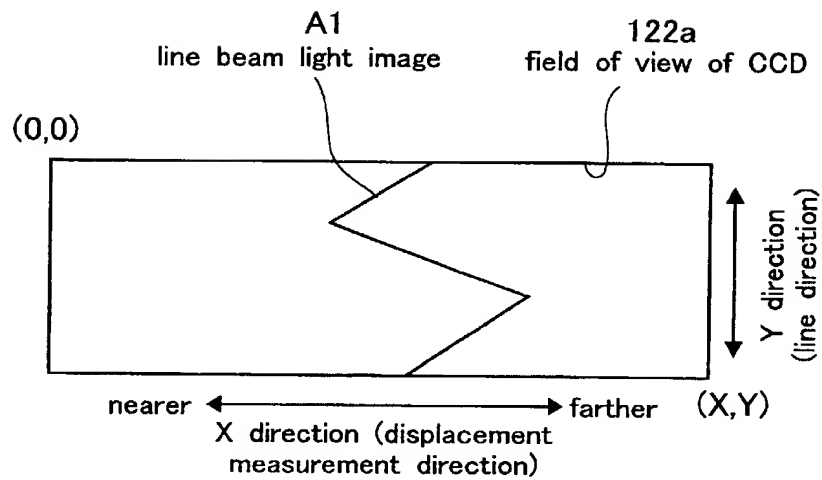
A view illustrating an image
captured by the CCD incorporated in the sensor head unit

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Fig. 7

A1
line beam
light image

122a
field of view of CCD

A2

peak position
(Px,Py)

(0,0)

A4
measurement
object range

bottom
position
(Bx,By)

Y direction
(line direction)

nearer ←————→ farther   (X,Y)

A3

X direction
(displacement
measurement direction)

A view illustrating the process of
extracting measurement points in a measurement object range

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Fig. 8

A1
line beam light image

122a
field of view of CCD

A2

(0,0)

A6

measurement
object range

Y direction
(line direction)

A4

A3

(X,Y)

gradation

A5
line bright waveform

displacement direction

A view illustrating the relationship
between the line bright waveform and the image captured by the CCD

09/937480

Fig. 9
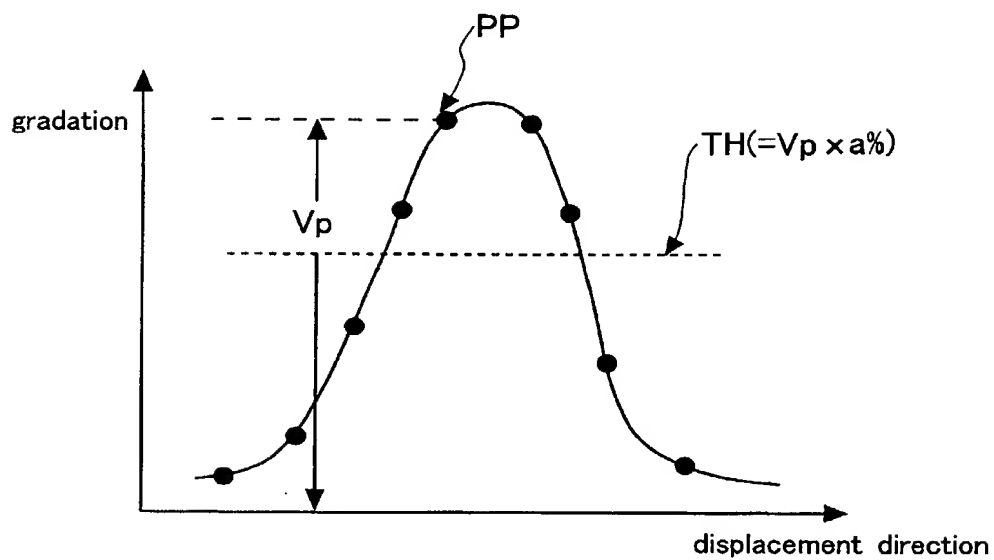
An illustrative view showing the process of determining the threshold value

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Inventor(s): Tatsuya Matsunaga, et al.
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Fig. 10

gradation

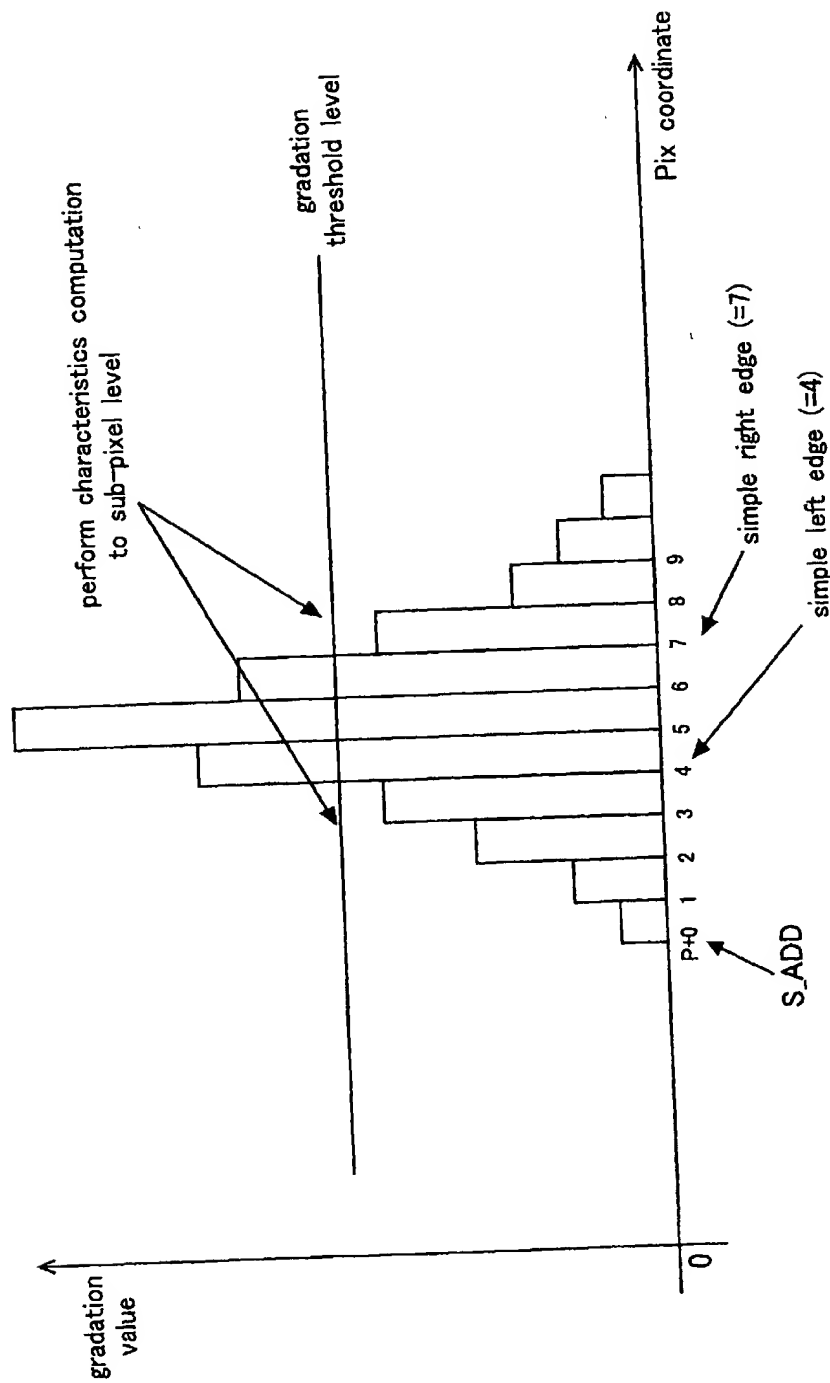centroid of gradation

TH

(a) centroid mode

measuring point

displacement

gradation

edge center

TH

(b) edge center mode

measuring point

displacement

gradation

side edge

TH

(c) side edge mode

measuring point

displacement
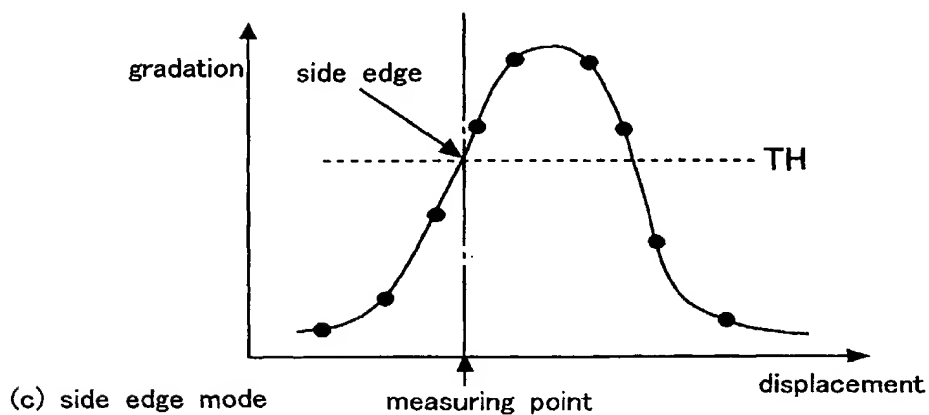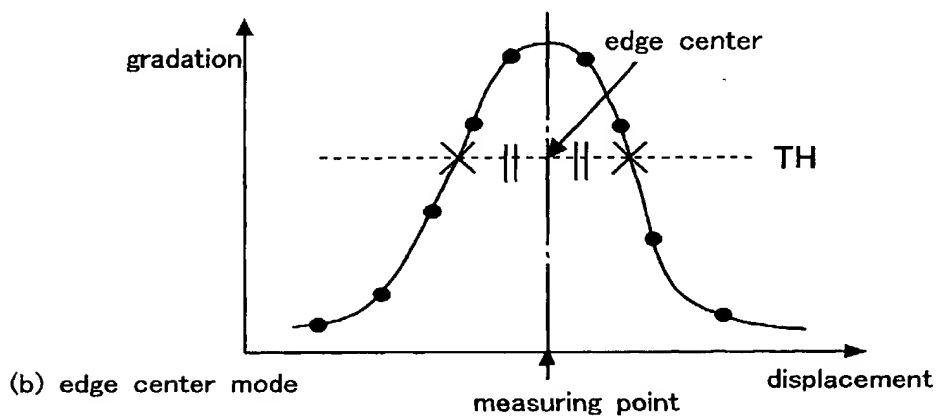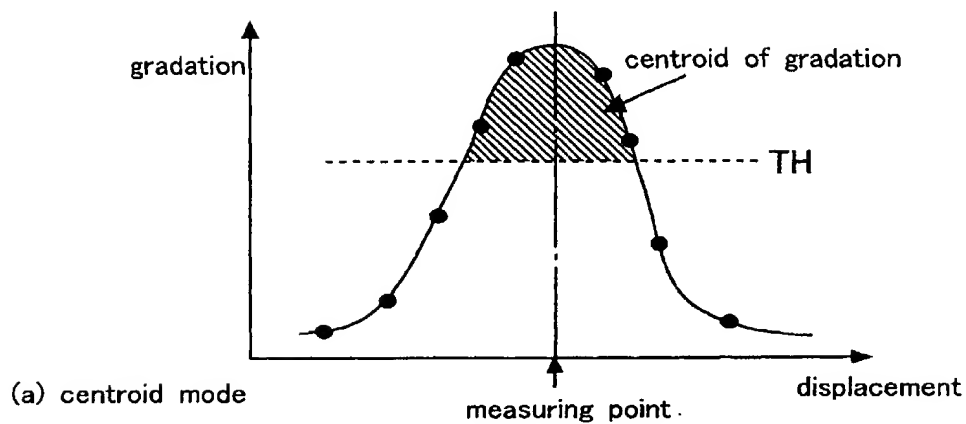
An illustrative view showing the process
of extracting the measuring point coordinate

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Fig. 11

image memory block (3) — (displacement value and determination references)

image memory block (2) — (line bright waveform and measuring point)

image memory block (1) — (frame determination values and fixed image components)

image memory block (0) — (raw image)
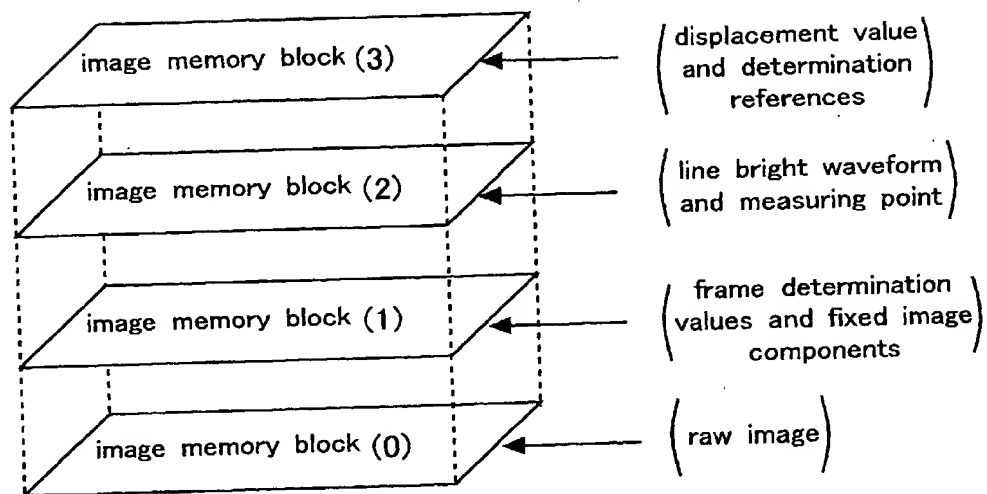
An illustrative view showing the process of generating the monitor display

Title: VISUAL DISPLACEMENT
SENSOR
Inventor(s): Tatsuya Matsunaga, et al.
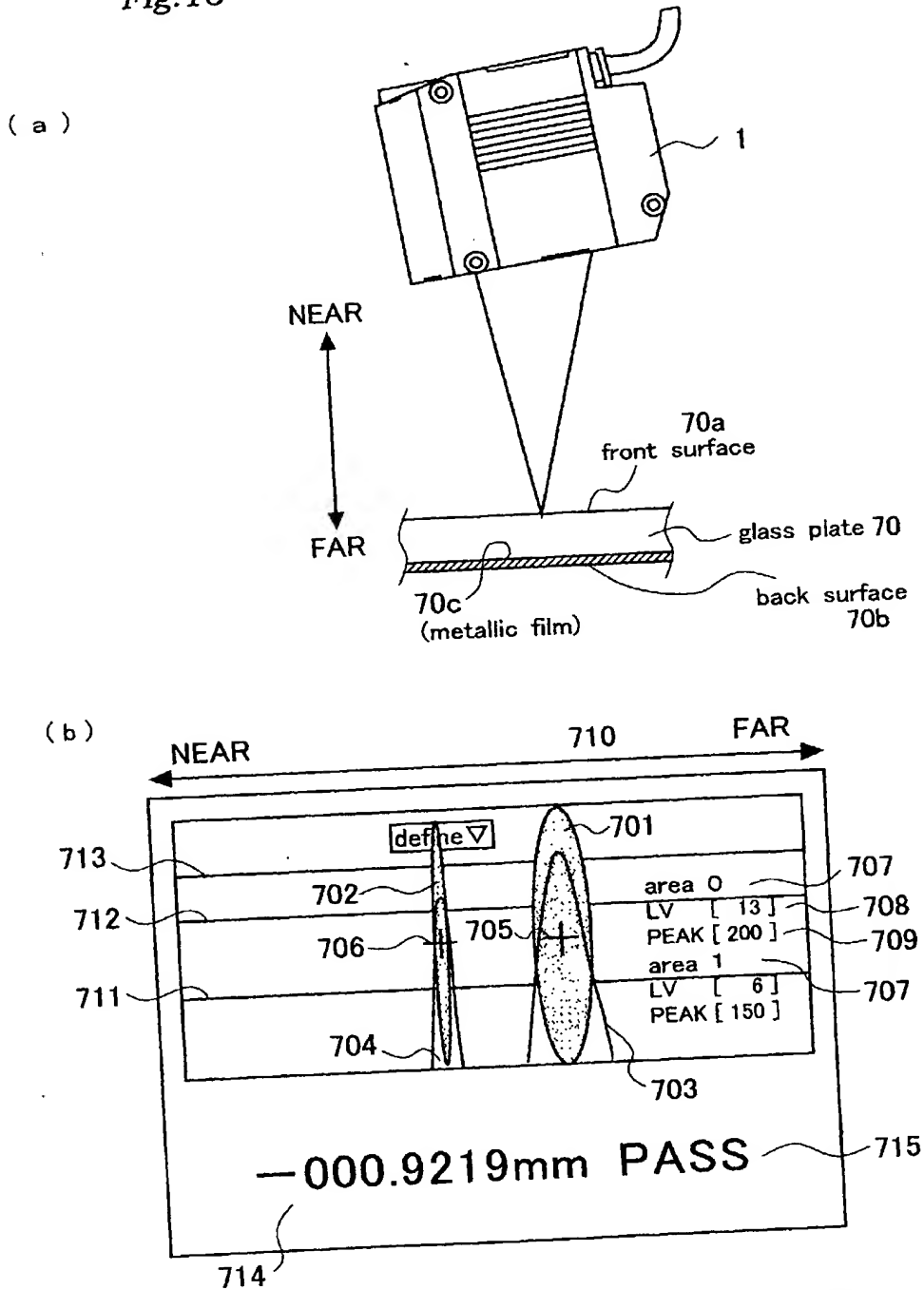DOCKET NO.: 058856-0106

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Fig.12
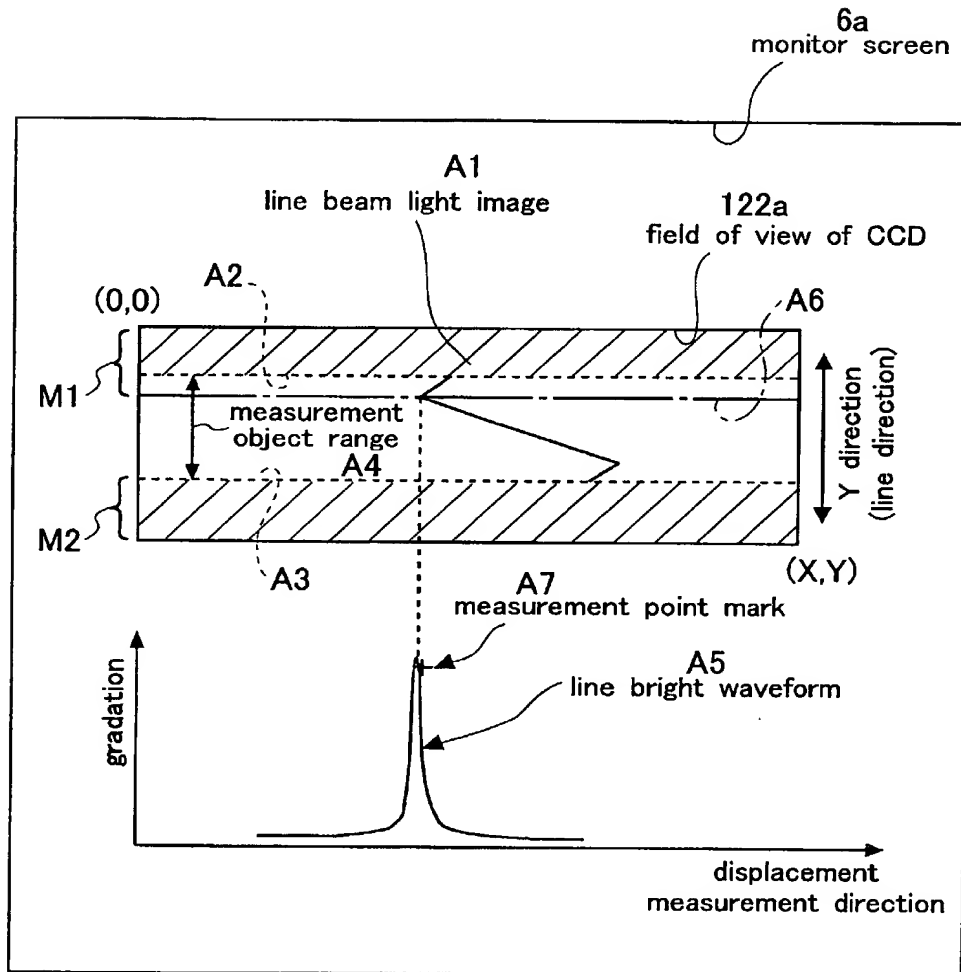
A view showing an exemplary monitor display showing the relationship
between the image captured by the CCD and line bright waveform

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SENSOR
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Fig. 13
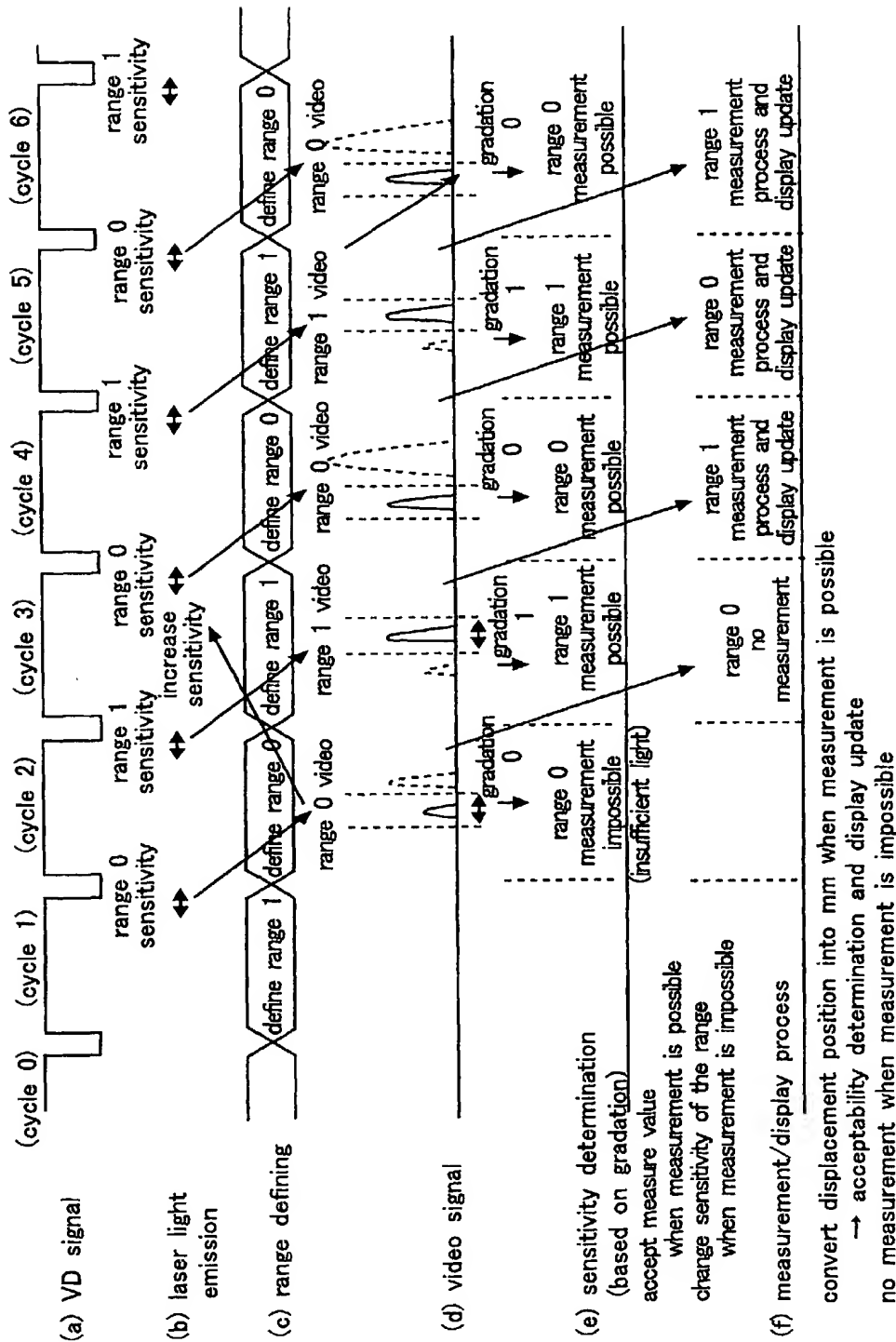
A time chart showing the gradation adjustment process for each range

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Fig.14
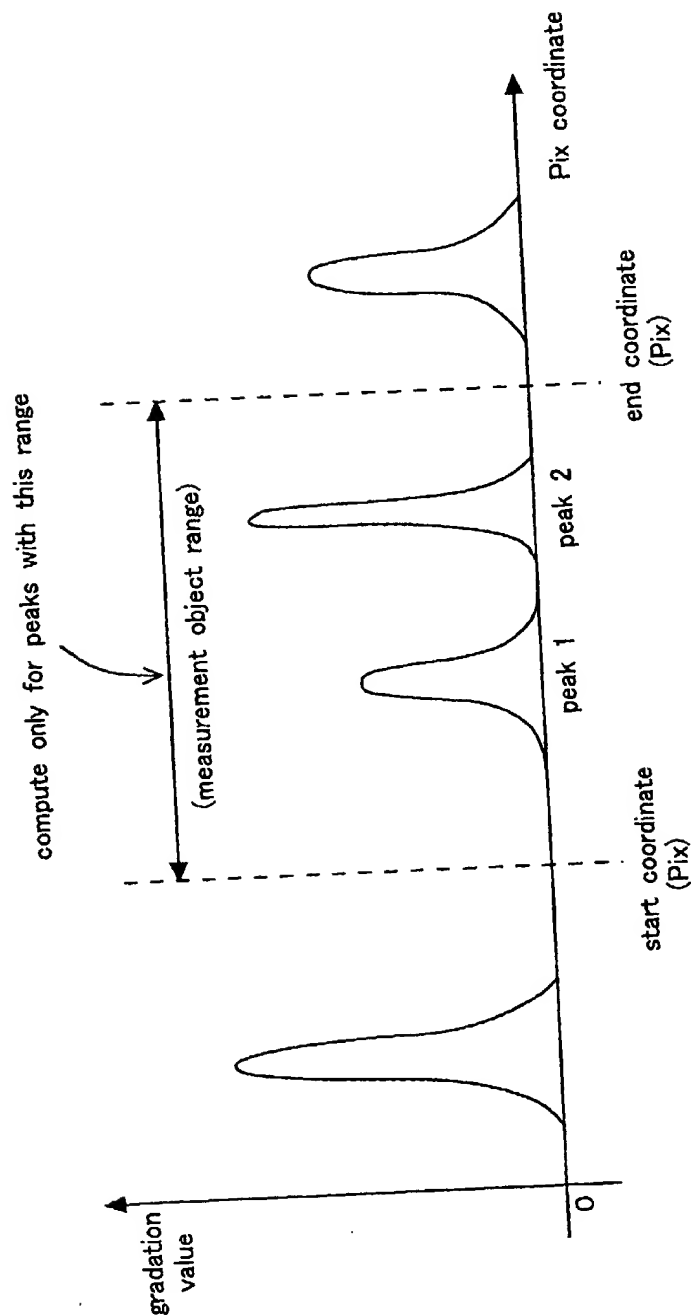
A view illustrating the relationship between the line bright waveform and measurement object range

Title: VISUAL DISPLACEMENT
SENSOR
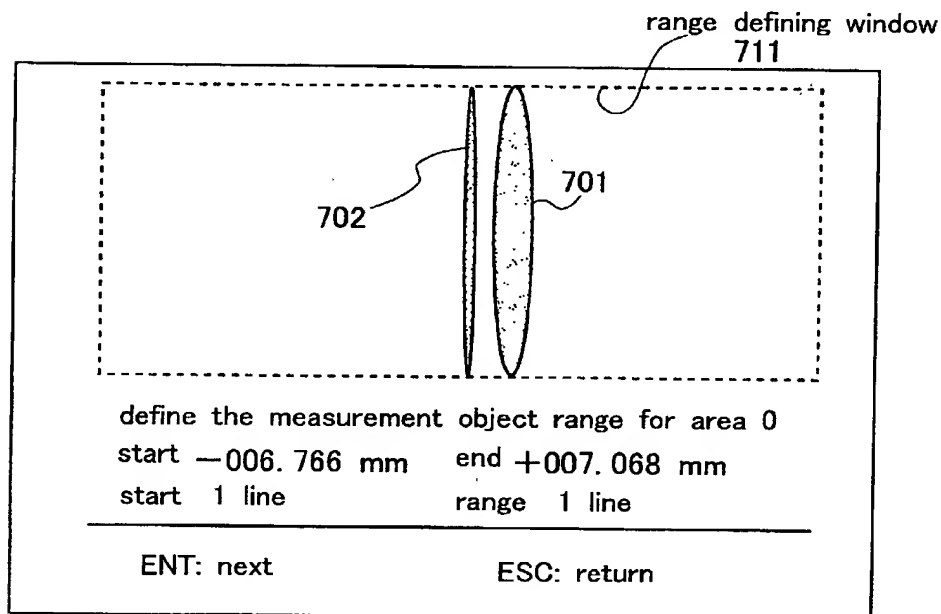Inventor(s): Tatsuya Matsunaga, et al.
DOCKET NO.: 058856-0106

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Fig.15

gradation
threshold level

perform characteristics computation
to sub-pixel level

Pix coordinate

simple right edge (=7)

simple left edge (=4)

gradation
value

S_ADD

P+0 1 2 3 4 5 6 7 8 9

0

A view illustrating the characteristic computation for determining measurement point coordinates

Fig.16

(a)

NEAR

FAR

70a
front surface

glass plate 70

70c
(metallic film)

back surface
70b

(b)

NEAR   710   FAR

713
712
711

702
706

705

704

define ▽

701

area 0
LV [13]
PEAK [200]

area 1
LV [6]
PEAK [150]

707
708
709

707

703

—000.9219mm PASS

714

715

a view showing a conventional measurement result

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Fig. 17

define ▼

1 range
2 ranges

701

702

select the number of ranges

ENT: next   ESC: return
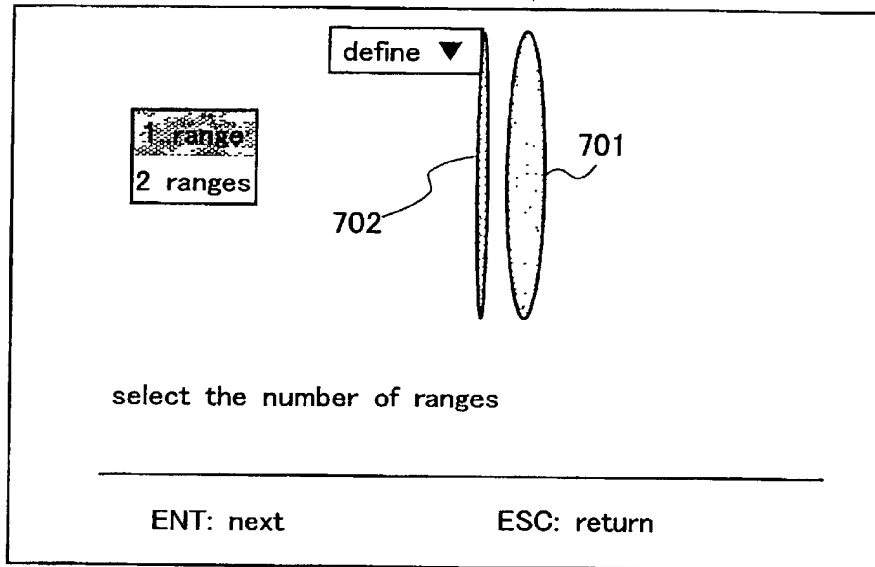
(a) selecting the number of ranges to be defined

range defining window
711

702   701

define the measurement object range for area 0
start —006. 766 mm   end +007. 068 mm
start 1 line   range 1 line

ENT: next   ESC: return

(b) defining measurement object range 0

A view illustrating the monitor screen when defining regions (part 1)

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Fig. 18

711

cursor
710

701

702

Z2

Z1

define the measurement object range for area 0

start —004. 266 mm   end +000. 068 mm

start   1 line   range   1 line

ENT: next   ESC: return

(a) defining measurement object range 0

711   711

702

701

define the measurement object range for area 1

start —006. 766 mm   end +007. 068 mm

start 1 line   range 1 line

ENT: next   ESC: return
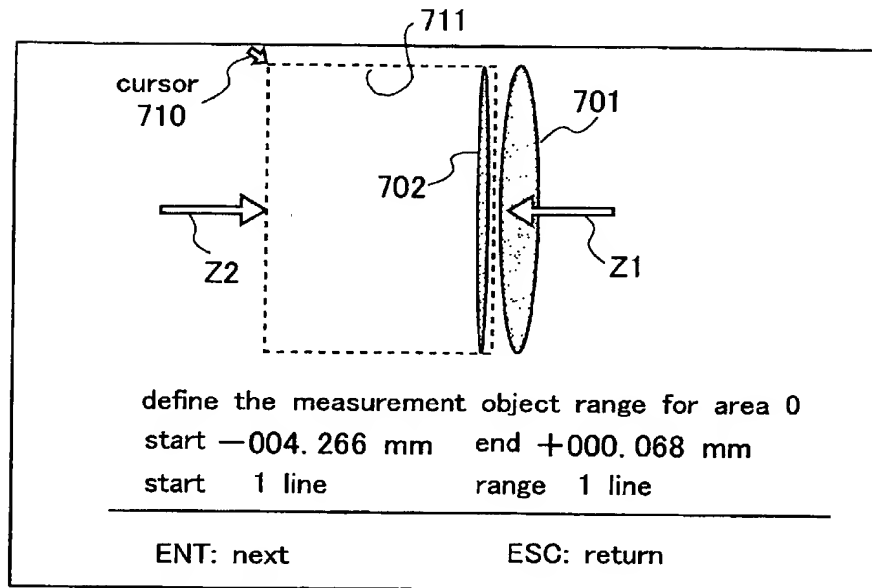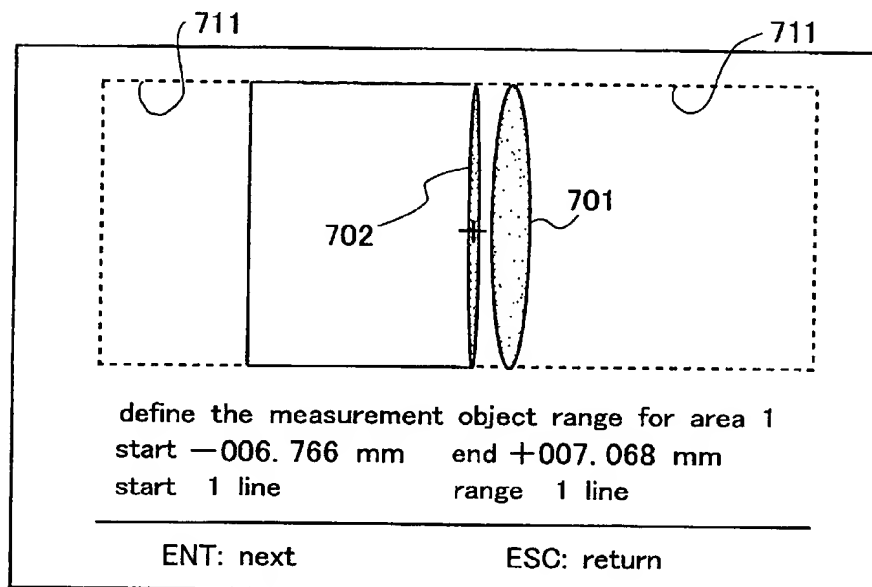
(b) complete the defining of measurement object range 0
(acquire a relative reference position)

A view illustrating the monitor screen when defining regions (part 2)

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Fig. 19

702   710   701

Z2   Z1

define the measurement object range for area 1
start —000. 033 mm   end +001. 268 mm
start   1 line   range   1 line

ENT: next   ESC: return
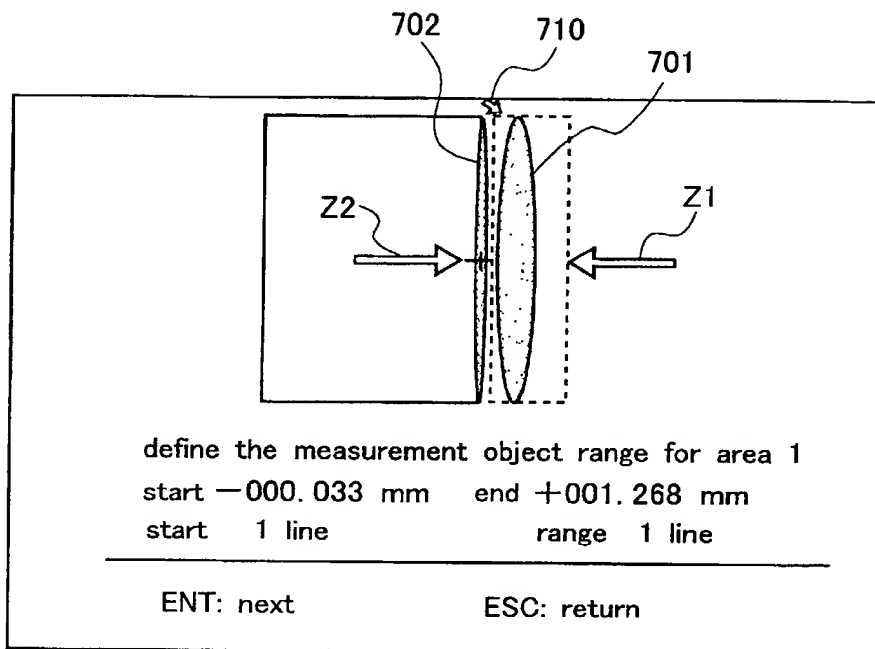
defining measurement object range 1
→ select only the back surface
for the measurement object range

A view illustrating the monitor screen when defining regions (part 3)

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Inventor(s): Tatsuya Matsunaga, et al.
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Fig.20

NEAR ← → FAR

710
707

713
712
711

define ▽ 706

702

area 0 708
LV [13] 709
PEAK [200]

701

area 1 707
LV [6] 708
PEAK [150] 709

704

703

705

+001.0000mm PASS 715

714
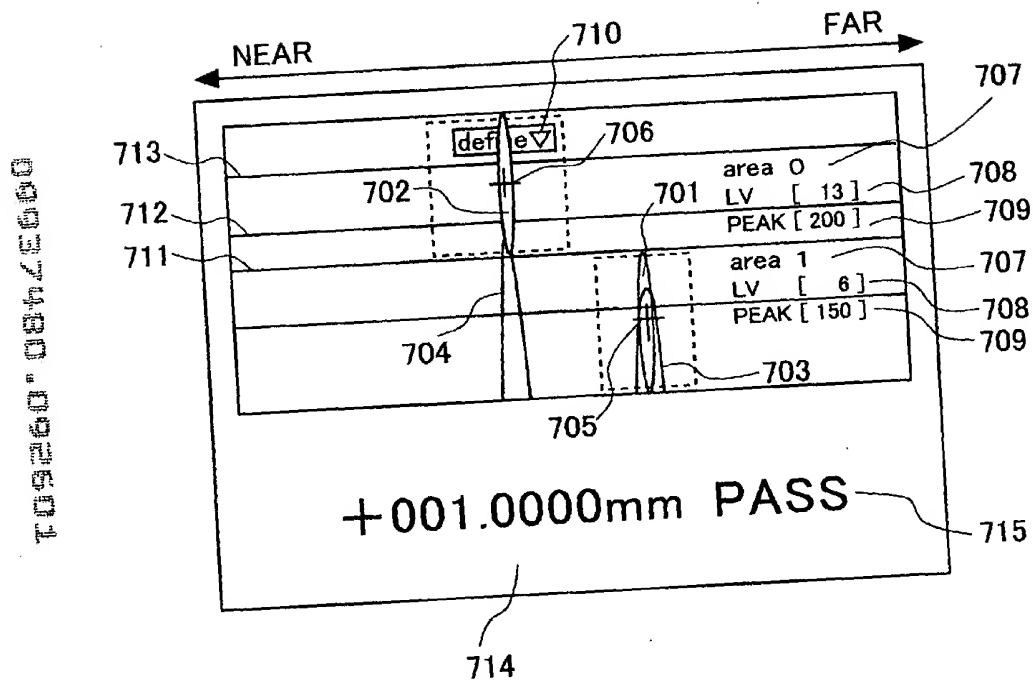
A view illustrating the monitor screen at the time
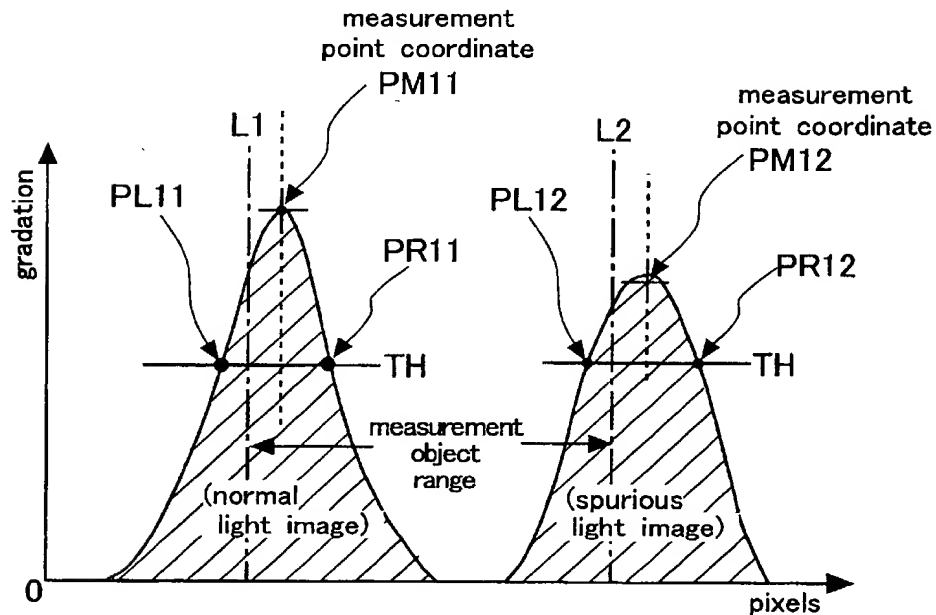of measurement after two measurement object ranges are defined

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Fig.21
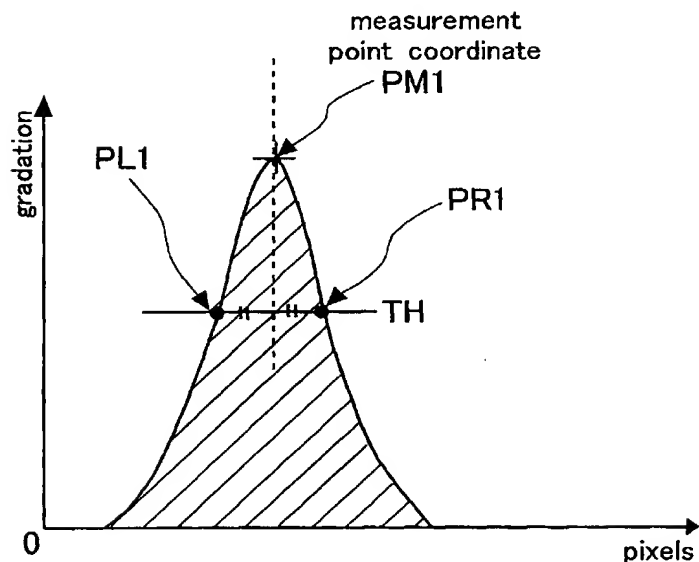
(a) measurement point coordinate extracted from the input image
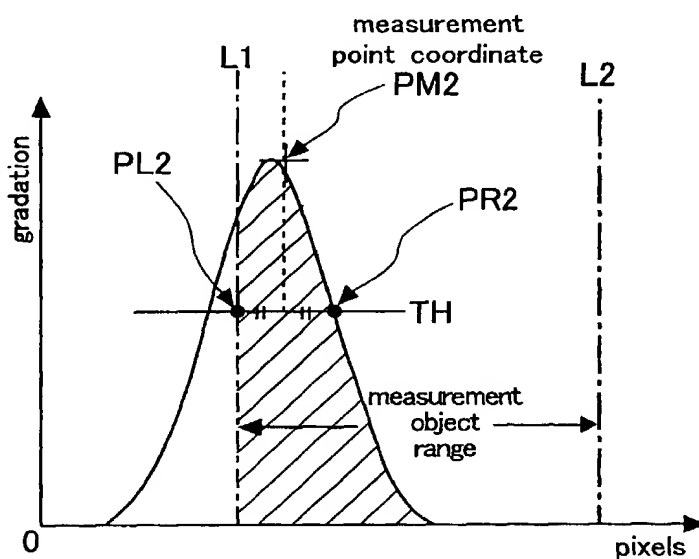
(b) measurement point coordinate extracted from the masked image

A view illustrating the problem with the process
of extracting a measurement point coordinate using a masked image

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Fig.22

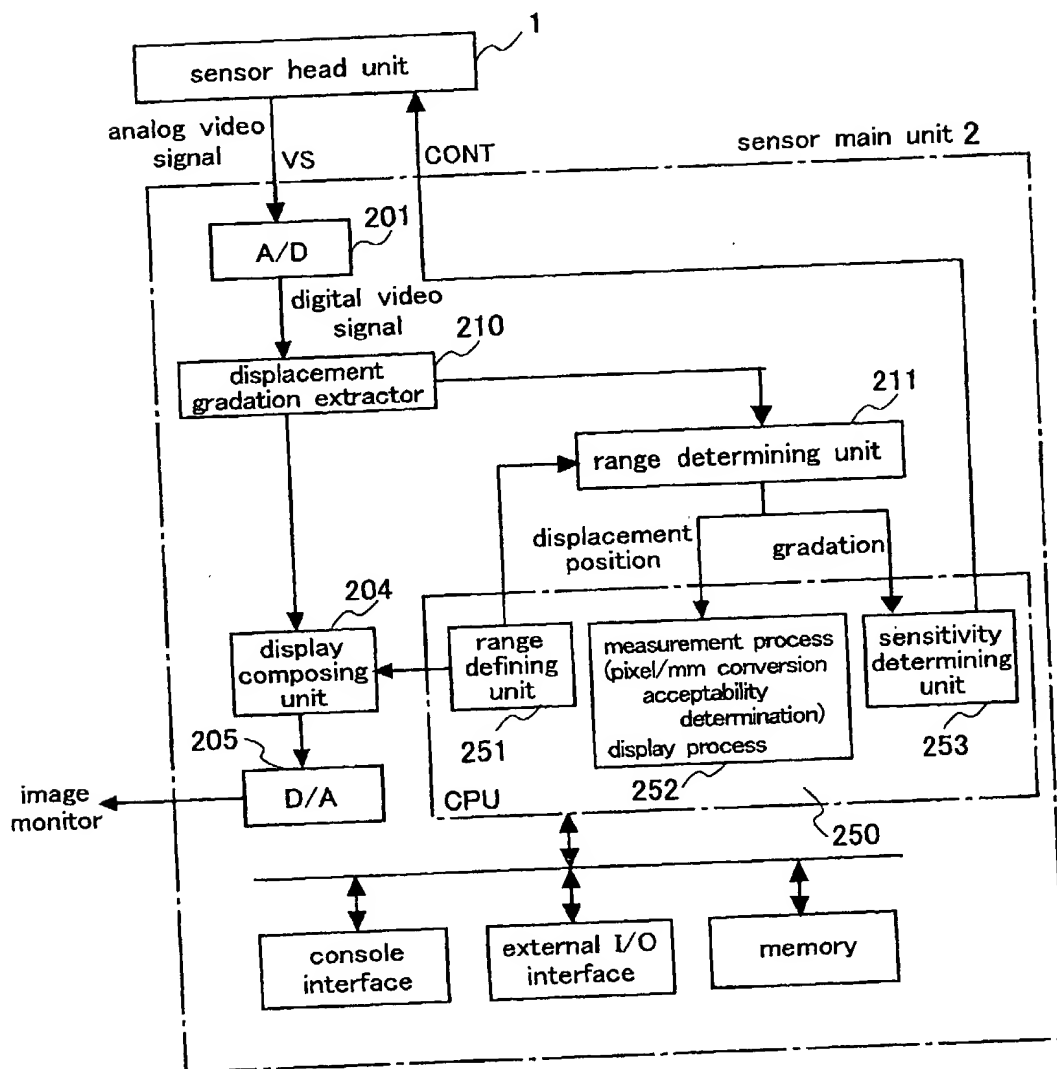(a) provisional decision of measurement point coordinates
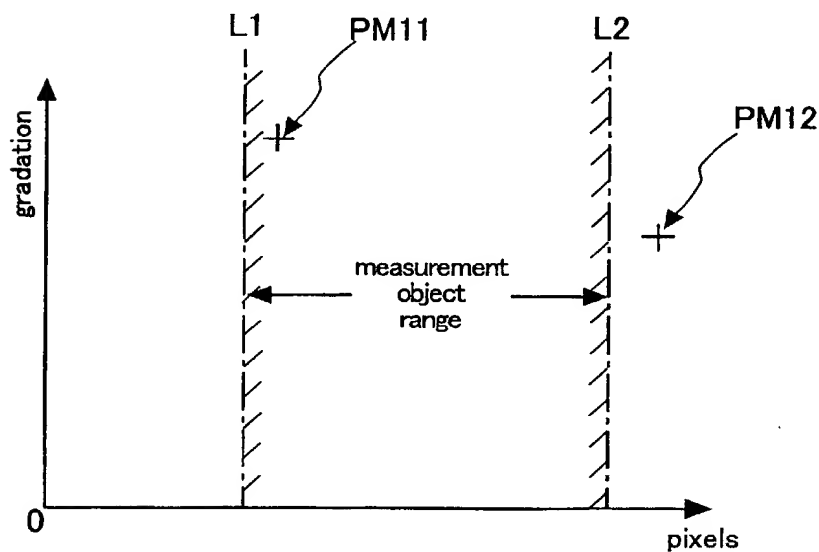
(b) formal decision of measurement point coordinates

A view illustrating the second embodiment of the process
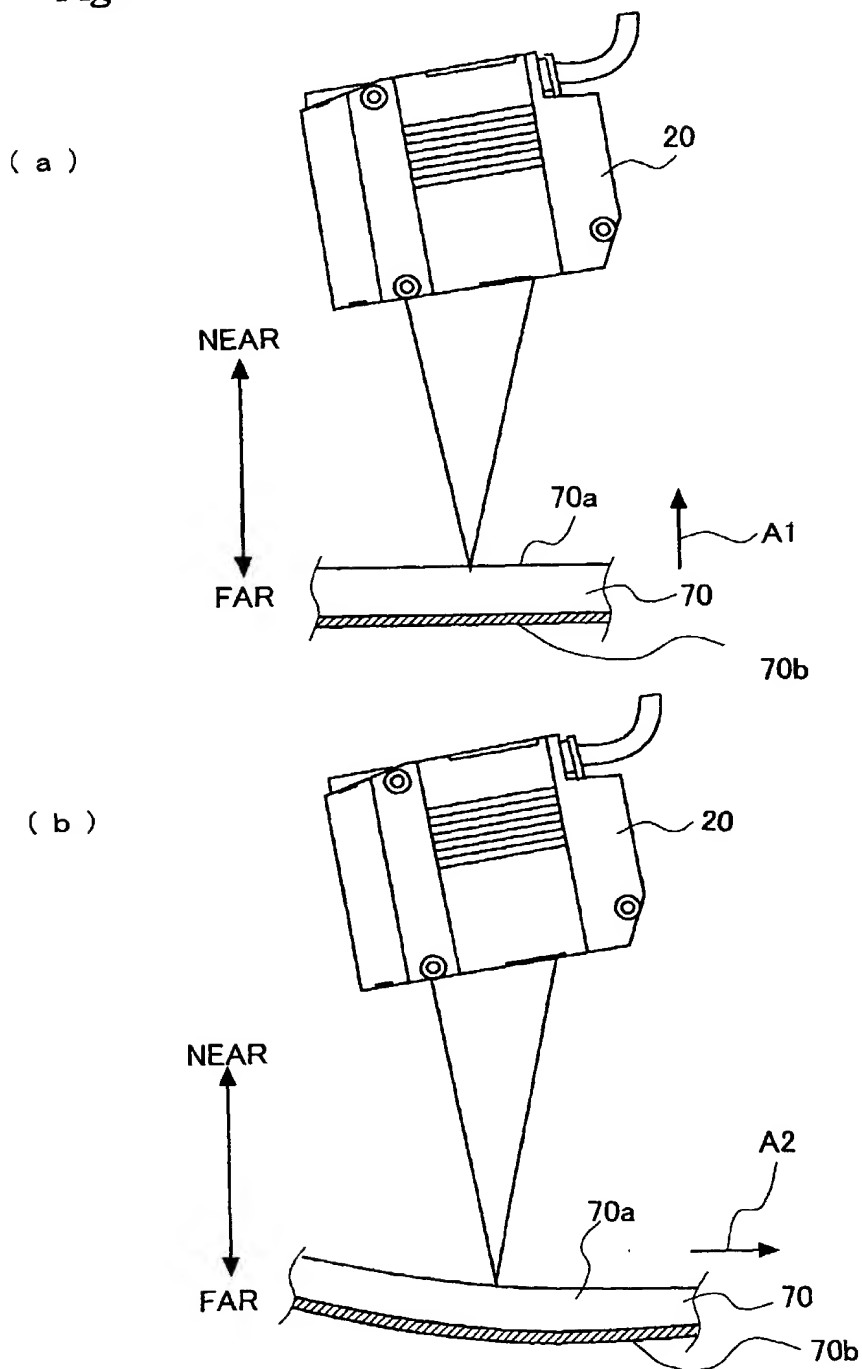of extracting a measurement point coordinate using a masked image

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09/937480

Fig.23

sensor head unit   1

analog video signal   VS   CONT   sensor main unit 2

A/D   201

digital video signal   210

displacement gradation extractor

211

range determining unit

displacement position   gradation

204

display composing unit

range defining unit

251

measurement process (pixel/mm conversion acceptability determination) display process

252

sensitivity determining unit

253

205

D/A   CPU   250

image monitor

console interface   external I/O interface   memory

A block diagram (part 2)
showing the functional internal structure of the sensor main unit

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Fig.24

(a)

NEAR

FAR

70a

A1

70

70b

20

(b)

NEAR

FAR

70a

A2

70

70b

20

A view showing a mode of vertical changes in a measurement point

Title: VISUAL DISPLACEMENT
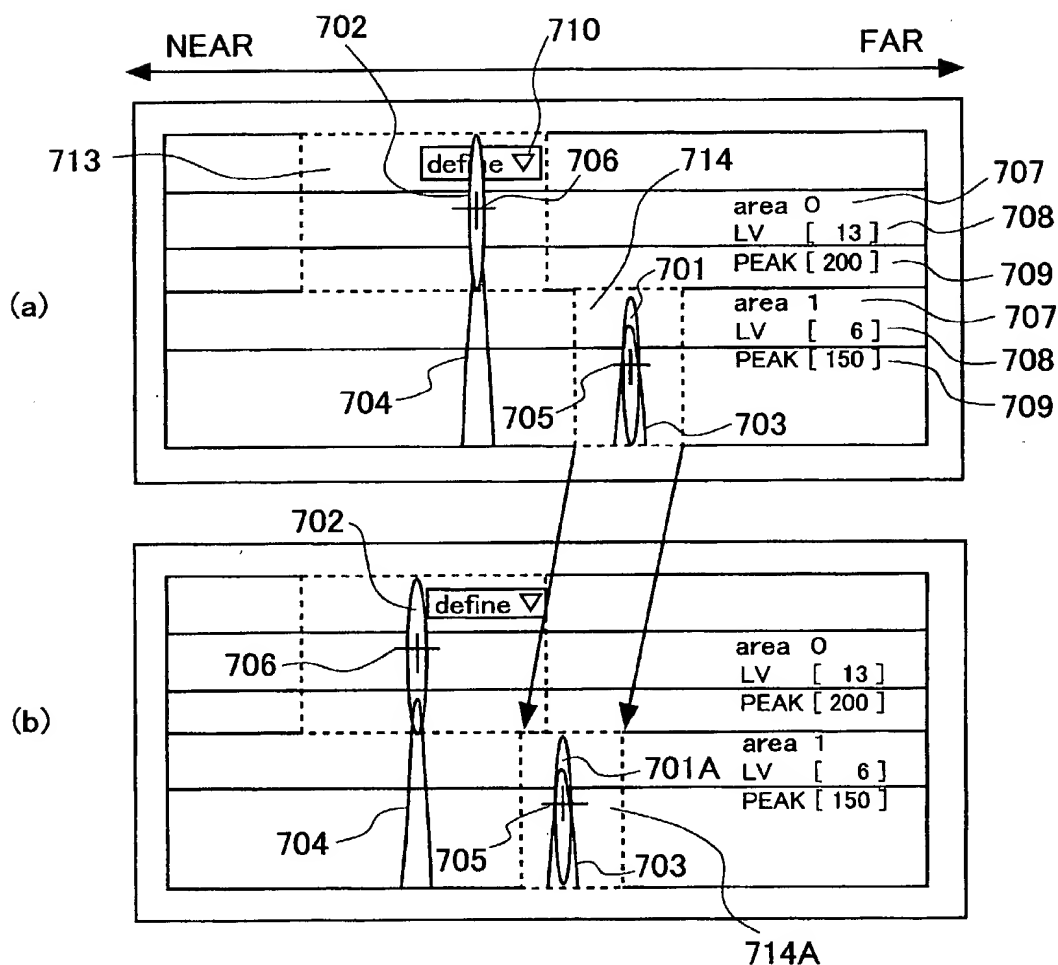SENSOR
Inventor(s): Tatsuya Matsunaga, et al.
DOCKET NO.: 058856-0106

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Fig.25
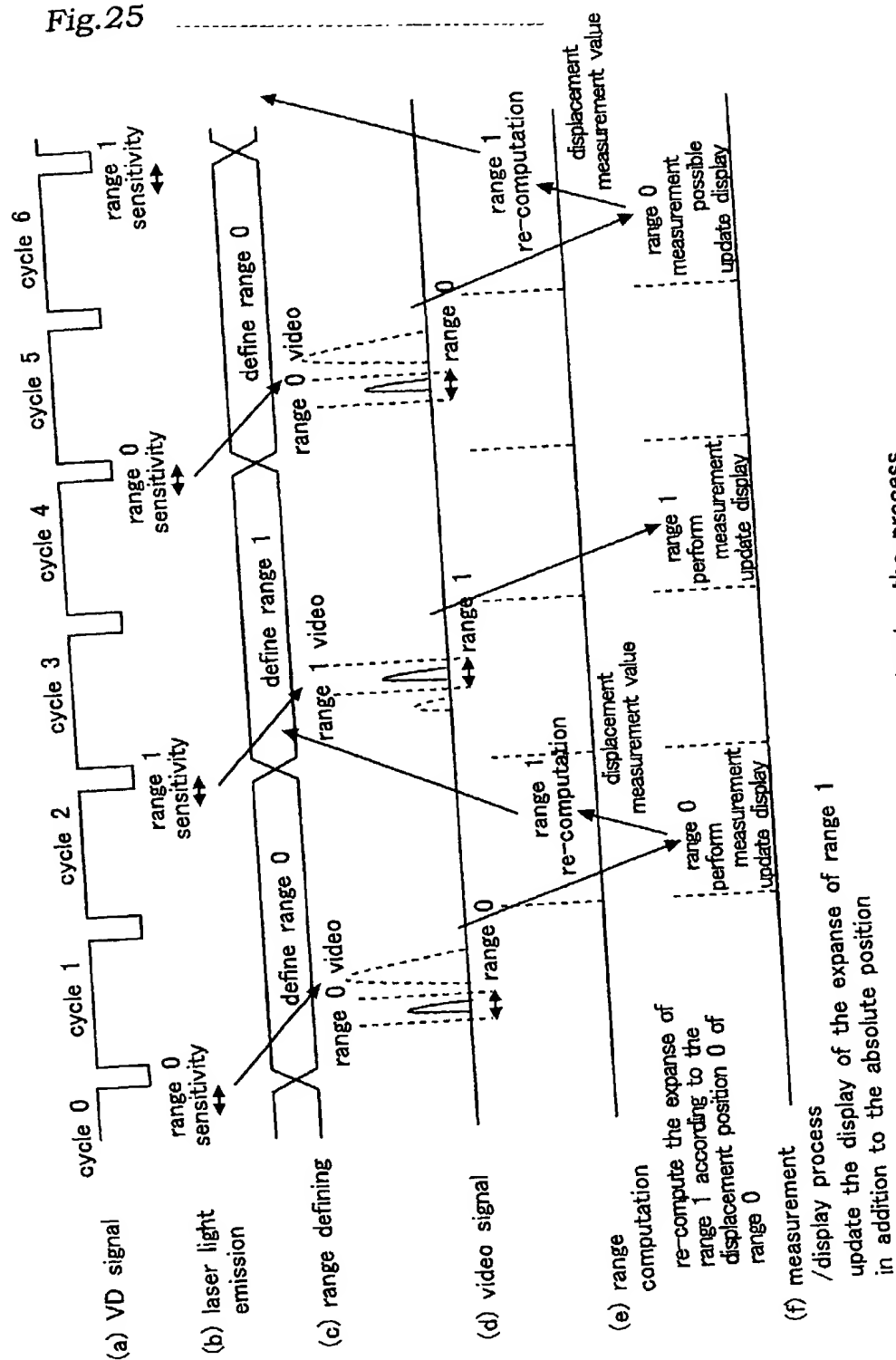
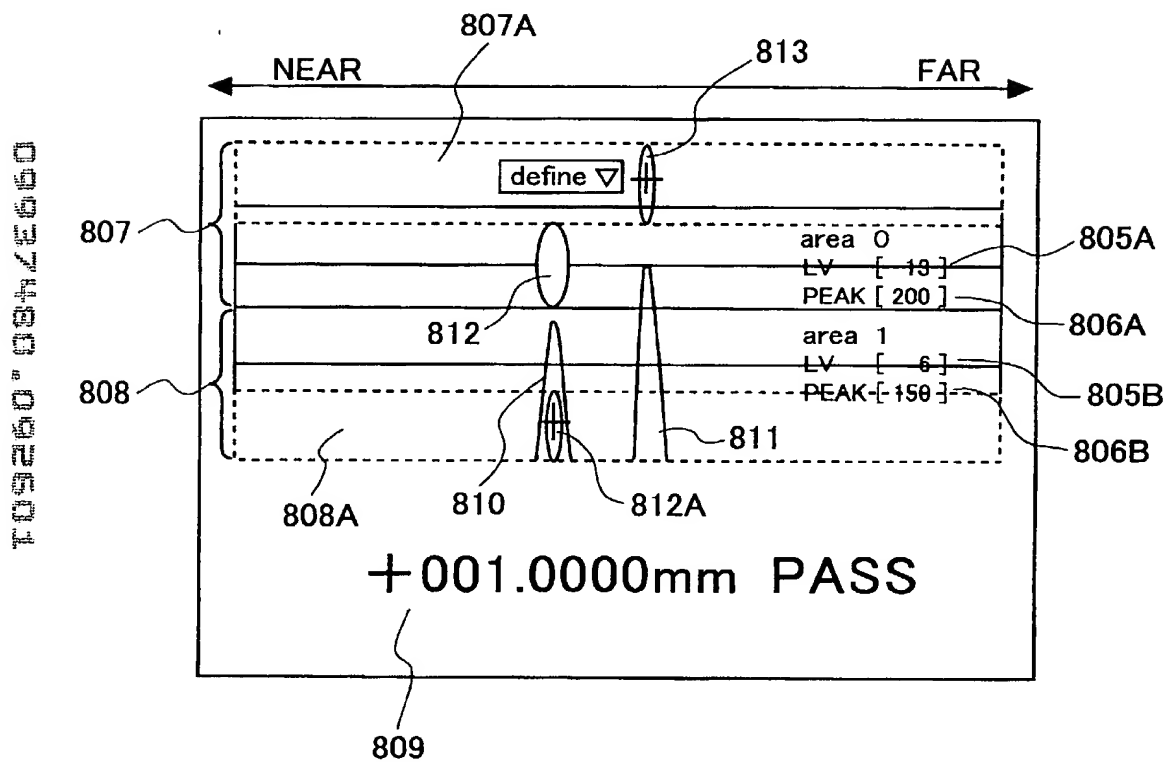A time chart showing the process of tracking defined regions to the vertical change in the measurement point

(a) VD signal

cycle 0 cycle 1 cycle 2 cycle 3 cycle 4 cycle 5 cycle 6

(b) laser light emission

range 0 sensitivity range 1 sensitivity range 0 sensitivity range 1 sensitivity range 0 sensitivity range 1 sensitivity

(c) range defining

define range 0 define range 1 define range 0

(d) video signal

range 0 video range 1 video range 0 video

range 0 range 1 range 0

(e) range computation

range 1 re-computation range 1 re-computation

displacement measurement value displacement measurement value

re-compute the expanse of range 1 according to the displacement position 0 of range 0

(f) measurement /display process

range 0
perform measurement;
update display

range 1
perform measurement;
update display

range 0
measurement possible
update display

update the display of the expanse of range 1 in addition to the absolute position

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Fig.26

A view showing the monitor screen
before and after the vertical change in the measurement point

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Fig.27

sensor head unit
1

line beam
804

NEAR

measurement
object 801

FAR

step size
803
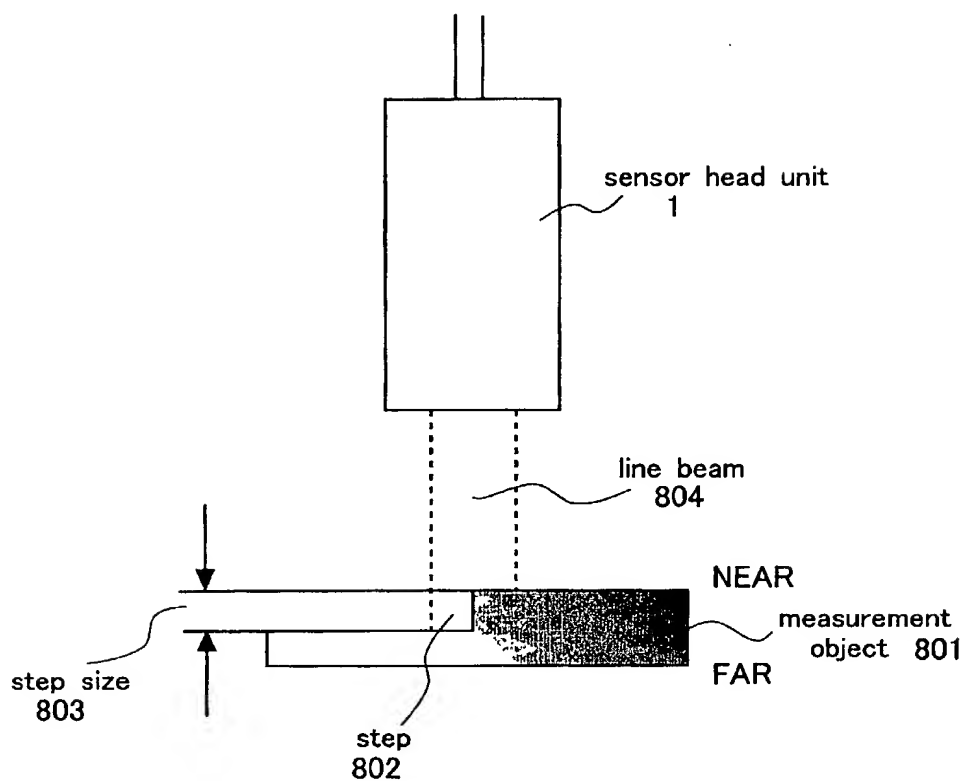
step
802

A view illustrating the positional relationship
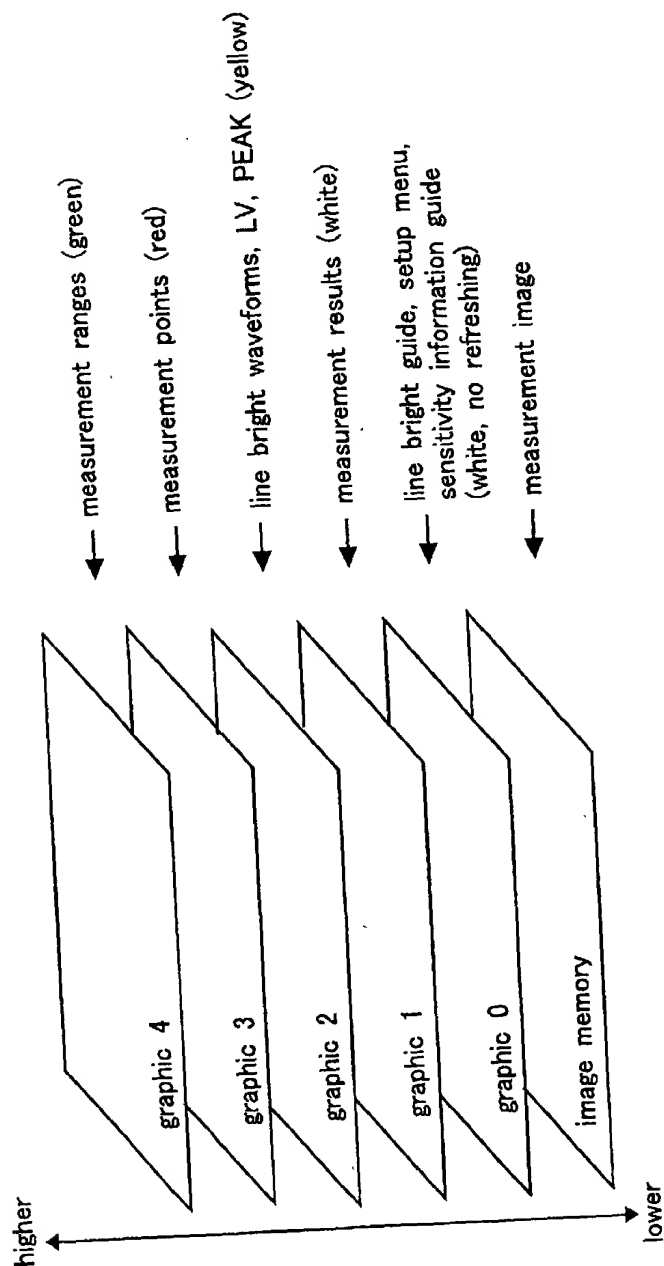between the sensor and measurement object when measuring a step

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Fig.28

A view showing the monitor screen for the measurement of a step

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Fig.29
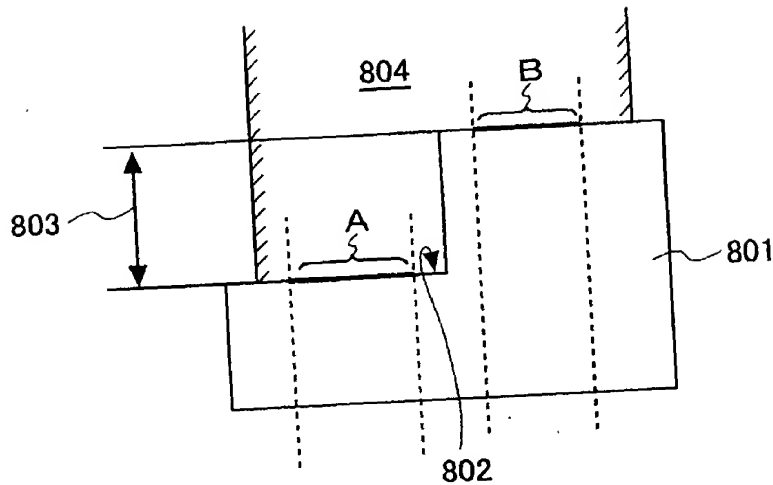
(a) when the measurement object is at the reference position
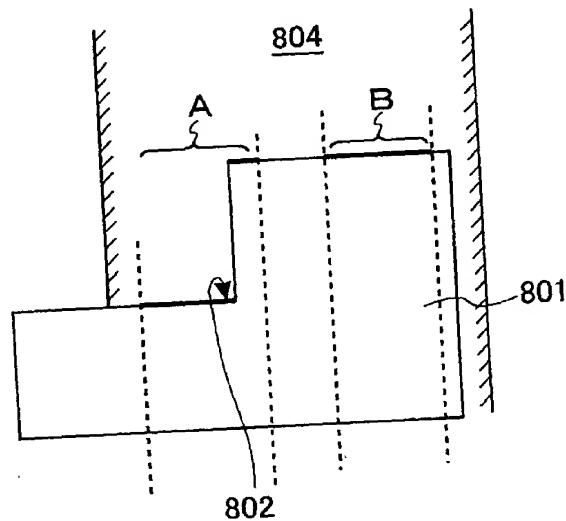
(b) when the measurement object has shifted laterally

A view illustrating the problem associated with the lateral shifting of the measurement object when measuring a step

Fig.30

(when the measurement object has shifted laterally)

(when the measurement object is at the reference position)

A view showing the control of tracking a lateral shift when measuring a step

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SENSOR
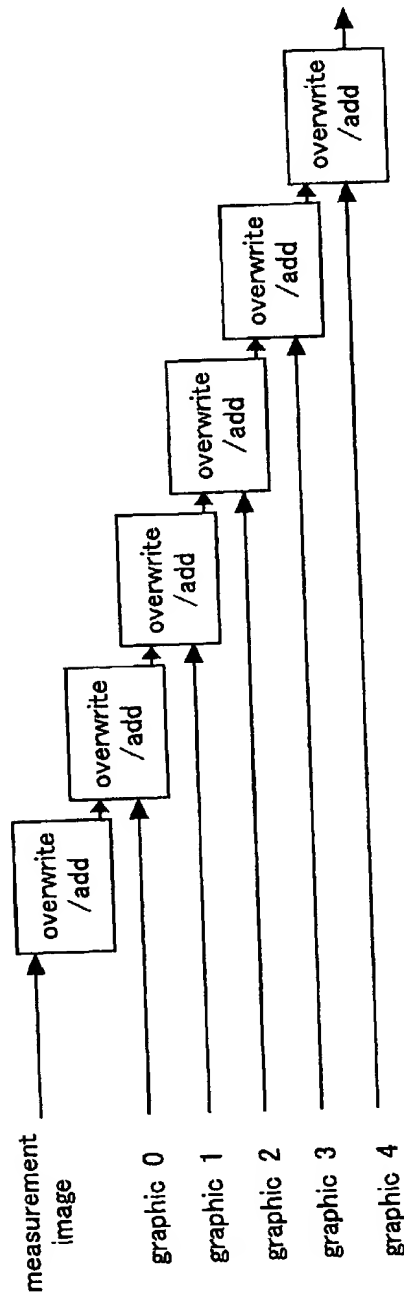Inventor(s): Tatsuya Matsunaga, et al.
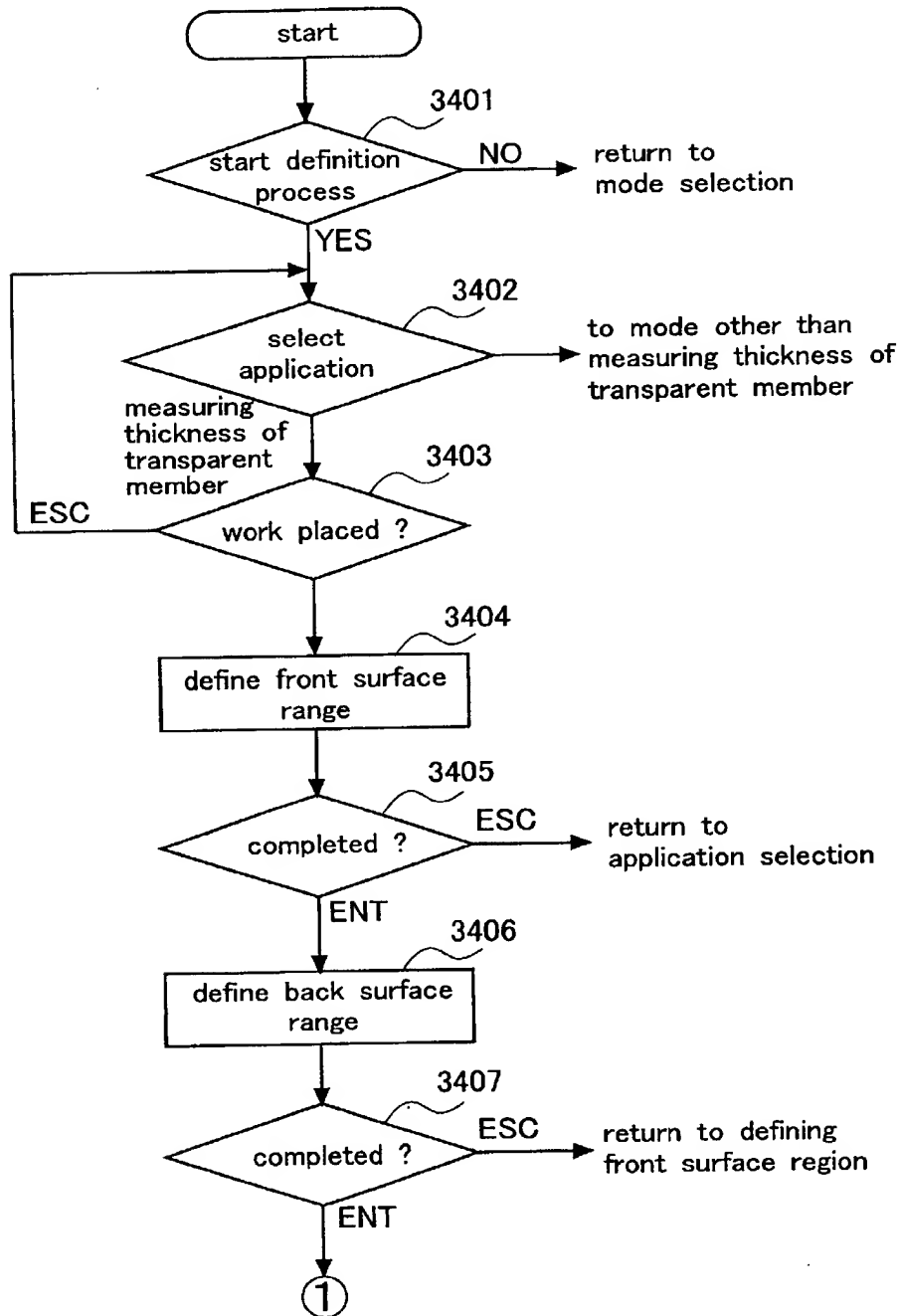DOCKET NO.: 058856-0106

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Fig.31
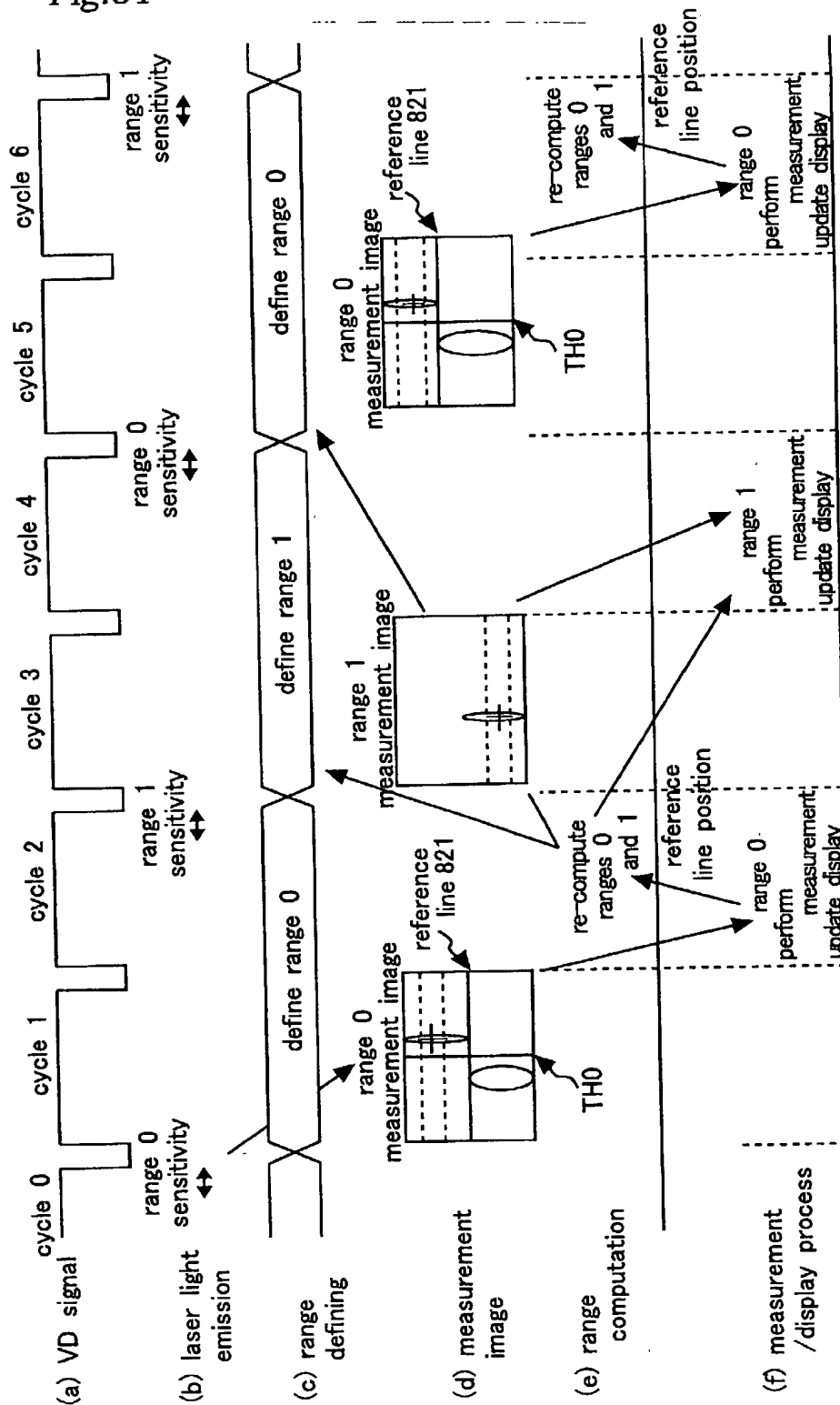
A time chart showing the flow of the control process
of tracking a lateral shift when measuring a step

Title: VISUAL DISPLACEMENT
SENSOR
Inventor(s): Tatsuya Matsunaga, et al.
DOCKET NO.: 058856-0106

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*Fig.*32

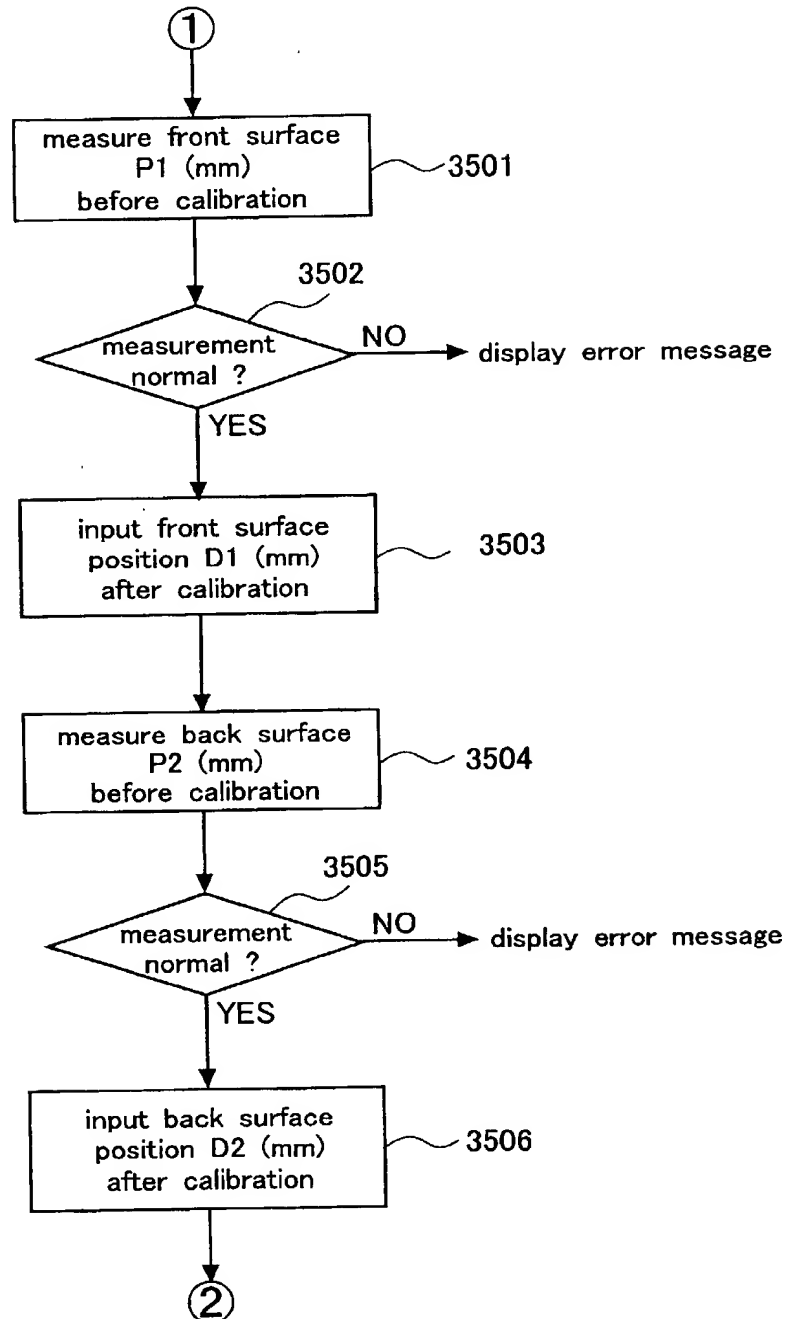A view illustrating the process of composing a display for the image monitor (part 1)

Title: VISUAL DISPLACEMENT
SENSOR
Inventor(s): Tatsuya Matsunaga, et al.
DOCKET NO.: 058856-0106

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Fig.33

measurement image

graphic 0

graphic 1

graphic 2

graphic 3

graphic 4

overwrite /add

A view illustrating the process of composing a display for the image monitor (part 2)

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Fig.34

start

3401

start definition process → NO → return to mode selection

YES

3402

select application → to mode other than measuring thickness of transparent member

measuring thickness of transparent member

3403

ESC

work placed ?

3404

define front surface range

3405

completed ? → ESC → return to application selection

ENT

3406

define back surface range
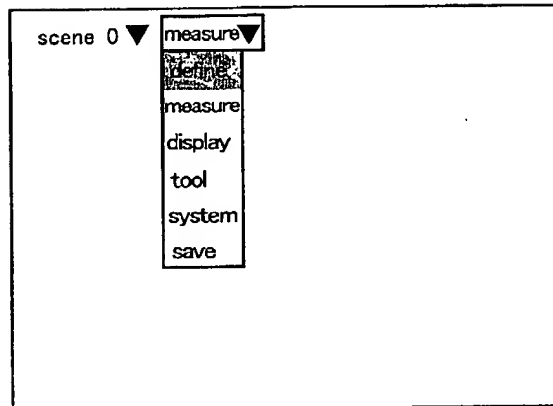
3407

completed ? → ESC → return to defining front surface region

ENT

①

A flow chart showing the calibration process
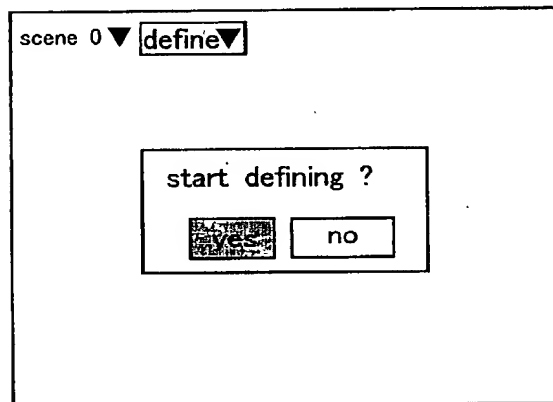for the computation of the thickness of a transparent member (part 1)

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Fig.35

①

measure front surface
P1 (mm)
before calibration —— 3501

3502

measurement
normal ? → **NO** → display error message

YES

input front surface
position D1 (mm)
after calibration —— 3503

measure back surface
P2 (mm)
before calibration —— 3504

3505

measurement
normal ? → **NO** → display error message

YES

input back surface
position D2 (mm)
after calibration —— 3506

②

A flow chart showing the calibration process
for the computation of the thickness of a transparent member (part 2)

Fig.36

②

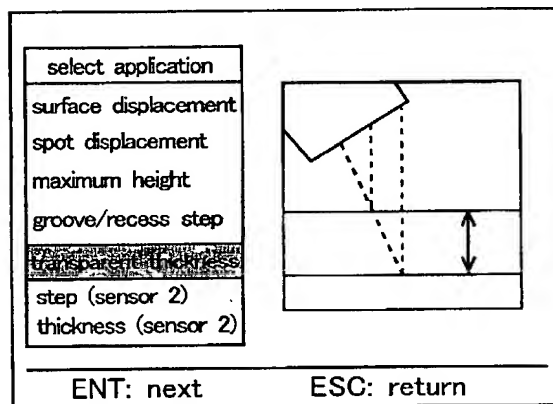**3601**
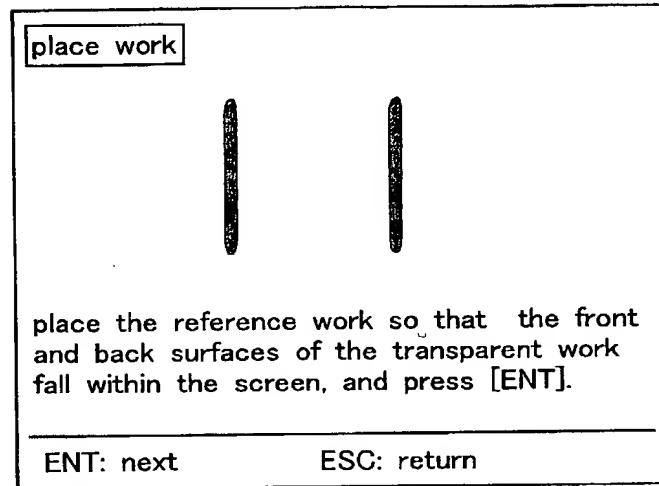
execute calibration

span

$$S = \frac{D2 - D1}{P2 - P1}$$

offset

$$O = D1 - \frac{D2 - D1}{P2 - P1} \times P1$$

3602

set OUT0 (thickness)
arithmetic equation

$$OUT0 = K + (A - B)$$

A=area 1 after calibration
B=area 0 after calibration

3603

set OUT1 (front surface)
arithmetic equation

$$OUT1 = K - A$$

A= area 0 before calibration

set OUT2 (front surface)
arithmetic equation

$$OUT2 = K - B1 - (A - B2)$$

B1=area 0 before calibration
B2=area 0 after calibration
A= area 1 after calibration

END

A flow chart showing the calibration process
for the computation of the thickness of a transparent member (part 3)

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SENSOR
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Fig.37

(a)

scene 0 ▼ | measure▼

define
measure
display
tool
system
save

(b)

scene 0 ▼ | define▼

start defining ?

yes | no

(c)

select application

surface displacement
spot displacement
maximum height
groove/recess step
transparent thickness
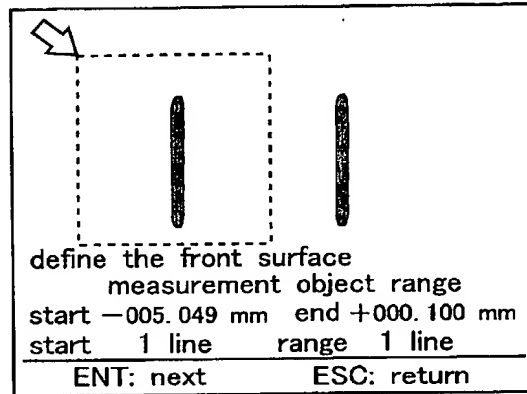step (sensor 2)
thickness (sensor 2)

ENT: next   ESC: return

A view showing the monitor screen for the calibration operation
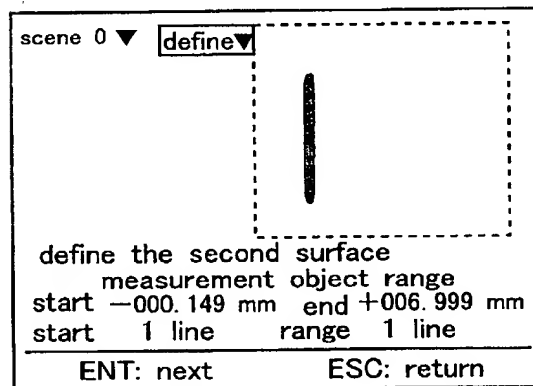for the computation of the thickness of a transparent member (part 1)

Fig.38

place work

place the reference work so that the front
and back surfaces of the transparent work
fall within the screen, and press [ENT].

ENT: next   ESC: return

(a)

front surface

back surface

transparent plate

(b)

A view showing the monitor screen for the calibration operation
for the computation of the thickness of a transparent member (part 2)

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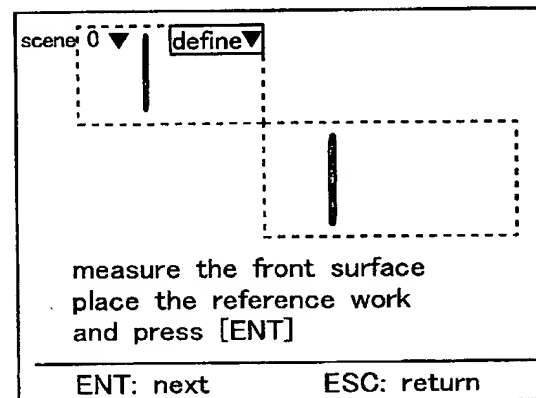
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Fig.39

(a)

define the front surface
     measurement object range
start —005. 049 mm   end +000. 100 mm
start   1 line   range   1 line

ENT: next   ESC: return

(b)

scene 0 ▼ define▼

define the second surface
     measurement object range
start —000. 149 mm   end +006. 999 mm
start   1 line   range   1 line

ENT: next   ESC: return

(c)
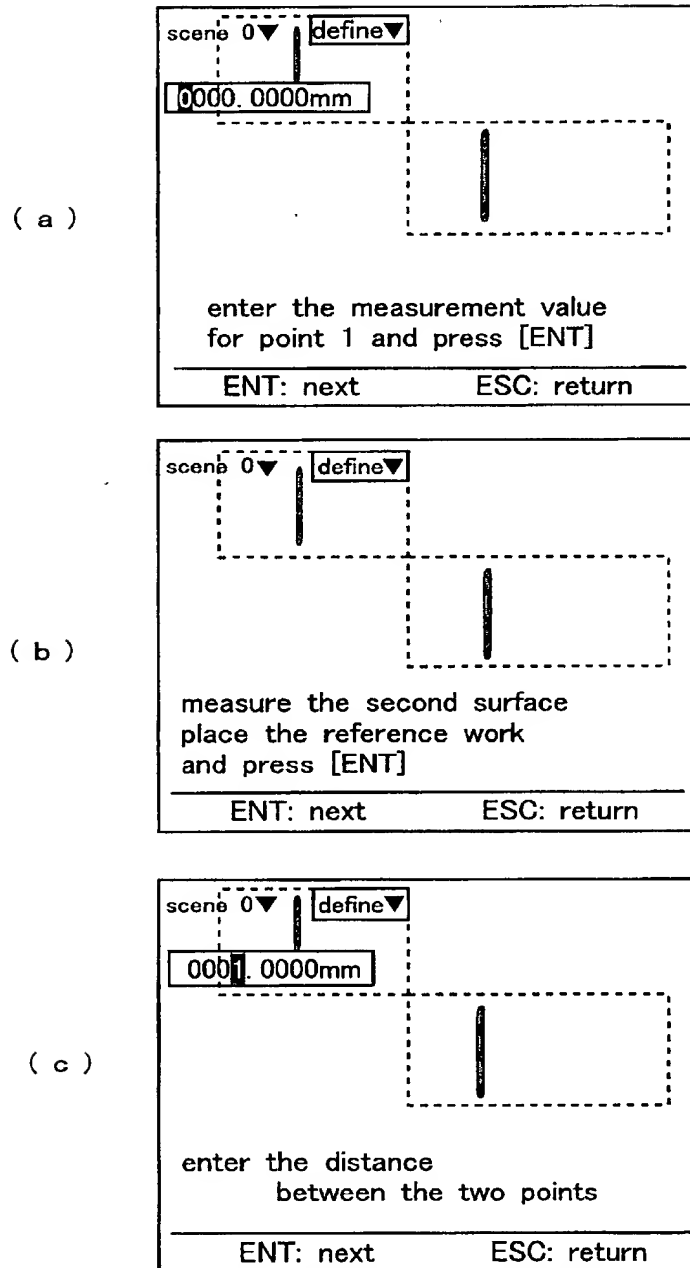
scene 0 ▼ define▼

measure the front surface
place the reference work
and press [ENT]

ENT: next   ESC: return

A view showing the monitor screen for the calibration operation
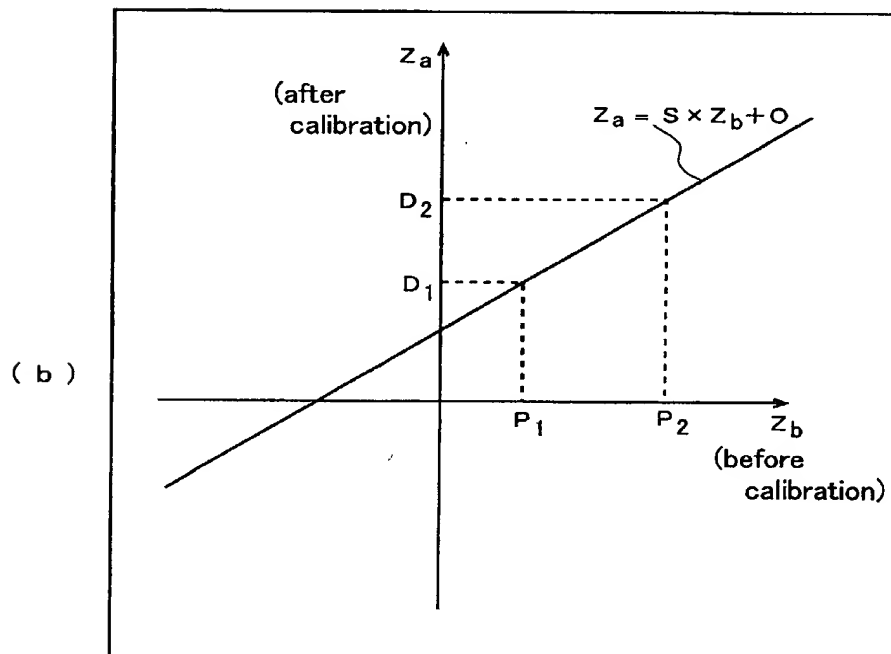for the computation of the thickness of a transparent member (part 3)

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Fig.40

(a)

```
scene 0▼   define▼

0000.0000mm



       enter the measurement value
       for point 1 and press [ENT]

       ENT: next        ESC: return
```

(b)

```
scene 0▼   define▼




   measure the second surface
   place the reference work
   and press [ENT]

       ENT: next        ESC: return
```

(c)

```
scene 0▼   define▼

0001.0000mm



       enter the distance
            between the two points

       ENT: next        ESC: return
```

A view showing the monitor screen for the calibration operation
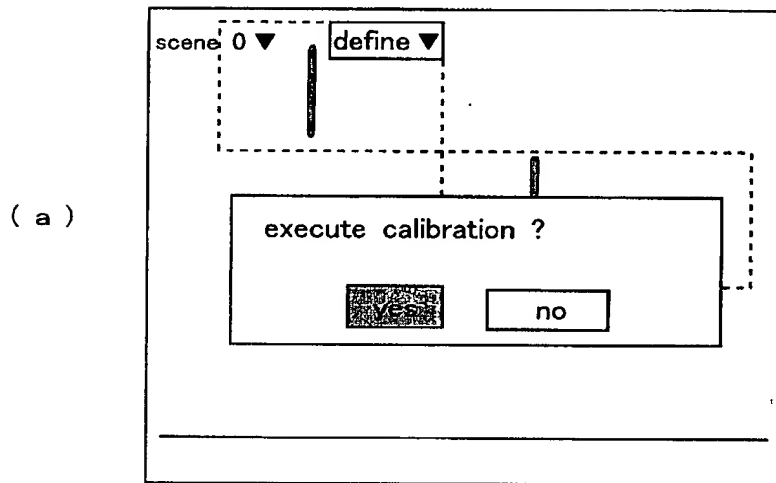for the computation of the thickness of a transparent member (part 4)

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Fig.41

(a)

scene 0 ▼   define ▼

execute calibration ?

YES   no

(b)

z_a

(after
calibration)

$z_a = S \times z_b + O$

D_2

D_1

P_1 P_2 z_b

(before
calibration)

A view showing the monitor screen for the calibration operation
for the computation of the thickness of a transparent member (part 5)

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Fig.42

(a)

accept definition / register
application   transparent plate
thickness
arithmetic $K + (A - B)$
equation $A = $ area
$B = $ area
register in OUT0

register   cancel   return

(b)

measurement of each point
can be allocated to the output
    front surface → OUT1
    back surface → OUT2

yes   no

(c)

definition complete
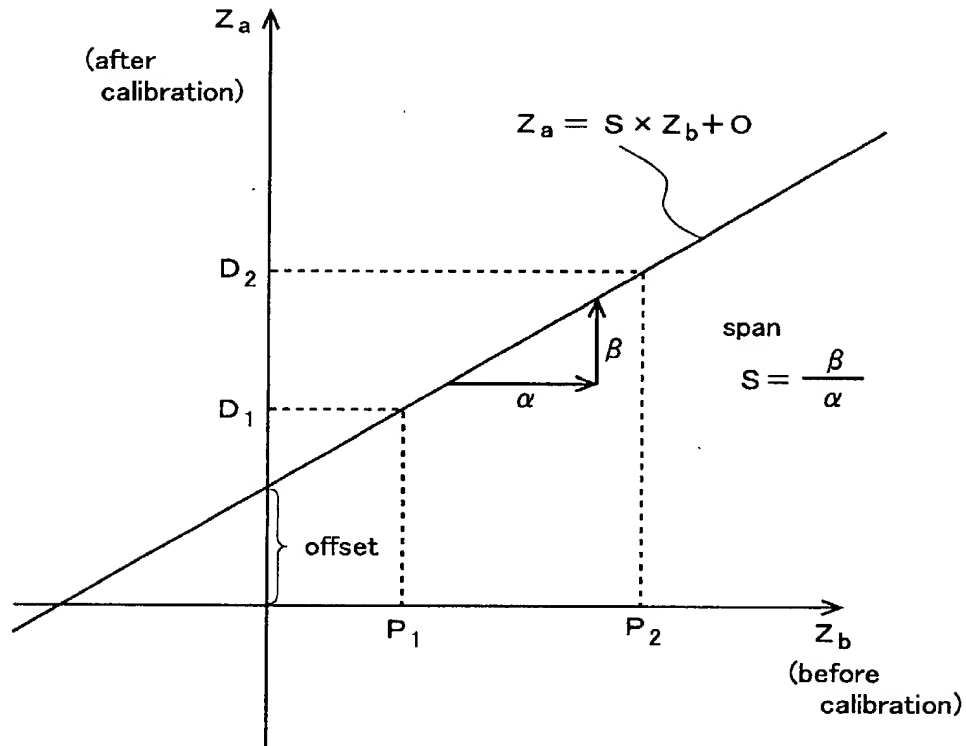proceed to
measurement mode

accept

A view showing the monitor screen for the calibration operation
for the computation of the thickness of a transparent member (part 6)

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Fig.43

$$Z_a = S \times Z_b + O$$

span

$$S = \frac{\beta}{\alpha}$$

offset

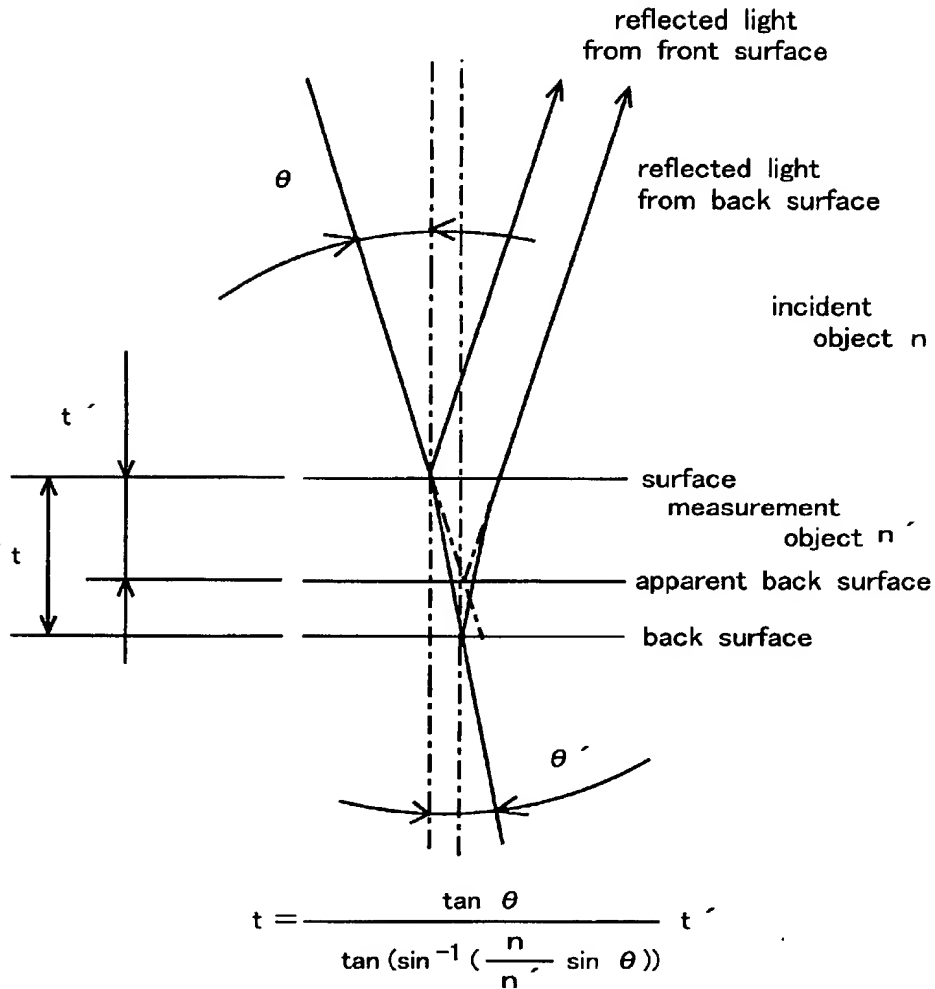$$S = \frac{D_2 - D_1}{P_2 - P_1}$$

$$O = D_1 - \frac{D_2 - D_1}{P_2 - P_1} \times P_1$$

A view showing the algorithm for the calibration operation
for the computation of the thickness of a transparent member

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Fig.44

reflected light
from front surface

reflected light
from back surface

incident
object n

θ

t ´

surface
measurement
object n ´

t

apparent back surface

back surface

θ ´

$$t = \frac{\tan \theta}{\tan \left(\sin^{-1} \left(\dfrac{n}{n´} \sin \theta \right) \right)} \, t´$$

t	: thickness of measurement object
t ´	: sensor output value
θ	: sensor light beam incident angle
n	: refractive index of incident object (n=1 normally air)
n ´	: refractive index of measurement object

refractive indices of typical transparent materials	
air : 1.002	acrylic : 1.48~1.575
glass : 1.48~1.55	polycarbonate : 1.586
water : 1.333	

A view illustrating the reason for requiring a calibration for the measurement
of the thickness of a transparent member by using the visual displacement sensor